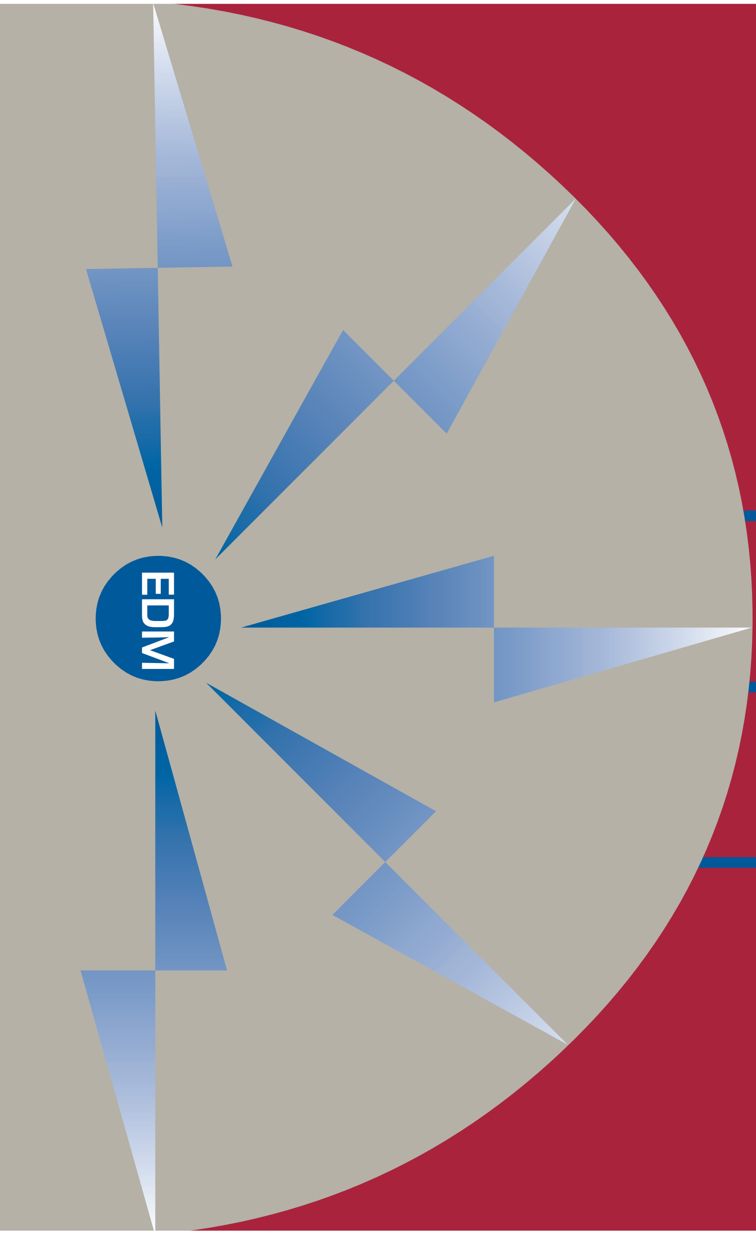

Electrical Discharge Machining

Elman C. Jameson

Jameson

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SME staff who participated in producing this book:
Phillip Mitchell, Senior Editor
Cheryl Zupan, Editor
Rosemary Csizmadia, Production Supervisor
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Dr. M. Sami Ahmed
HonD.Sc., Ph.D., B.Sc. (Eng), B.Sc. (Phys), F.I.EE., C.Eng.
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About SME

The Society of Manufacturing Engineers (SME), headquartered in Dearborn, Mich., is the world's leading professional society serving the manufacturing industries. Through its publications, expositions, professional development resources, and member programs, SME influences more than 500,000 manufacturing executives, managers, and engineers. Founded in 1932, SME has members in 70 countries and supports a network of hundreds of chapters worldwide.

About MTA/SME

The Machining Technology Association of SME (MTA/SME) supports the SME mission and serves its members and the global manufacturing community by identifying innovative technologies, business developments, and emerging trends in machining and grinding; assessing their potential impact on industry and society; and advising/assisting SME in the development of quality products and services in these areas. MTA provides a forum for exploring the practical application of material removal processes such as turning, milling, and grinding, and the machines and tooling used in these processes.

Preface

The author started working with Electrical Discharge Machining (EDM) almost as soon as the process was recognized in the USA—back when EDM-power supplies used vacuum tubes. During those early days, the author had the privilege of knowing and working with Victor Harding and Harold Stark, two of the engineers who originated and developed EDM as a process in the United States.

Over the next three decades, the author was involved in EDM-product design, training-school instruction, and application engineering. In working with the users of EDM machines, it was obvious that many of the people had little or no knowledge of electricity or electronics. It became necessary to describe the EDM-machine operations using sketches and very basic electrical and electronic terms. This book is a result of the information developed over those years.

In writing this text, the author has focused on EDM fundamentals. These are the items common to all EDM machines: the spark, how the spark is controlled, what causes overcut, and the importance of the dielectric fluid. With regard to the workpiece, attention is given to the effect the spark has on the metallurgy, how the surface finish is produced and controlled, and how the automatic-servo system operates.

Since the book's focus is on the fundamental elements of EDM, process applications and process control had to be excluded. Automatic-EDM machine-system controls were also excluded. Although computer control is necessary for today's wire-cut-EDM machining—and is the primary reason for the acceptance of the process in industry—all EDM-machine manufacturers have developed their own computer control and artificial intelligence features. These items are usually proprietary to the manufacturer and, as such, not fundamental to all EDM-machining systems. While these features greatly assist the EDM machinist, they are not critical to developing an understanding of the EDM process. Even so, it should be remembered that viewing

the process without the control features presents only a partial-EDM picture.

It is the author's hope that this text will serve as the primer on the EDM-machining process, allowing users of EDM to become more efficient and their machines more productive.

1 Description and Development of Electrical Discharge Machining (EDM)

DEFINITION OF EDM

Electrical Discharge Machining (EDM) is the process of machining electrically conductive materials by using precisely controlled sparks that occur between an electrode and a workpiece in the presence of a dielectric fluid. The electrode may be considered the cutting tool. Figure 1-1 illustrates the basic components of the EDM process.

Die-sinking (also known as ram) type EDM machines require the electrode to be machined in the exact opposite shape as the one in the workpiece. *Wire-cut* EDM machines use a continuous wire as the electrode. Sparking takes place from the electrode wire-side surface to the workpiece.

EDM differs from most chip-making machining operations in that the electrode does not make physical contact with the workpiece for material removal. Since the electrode does not contact the workpiece, EDM has no tool force. The electrode must always be spaced away from the workpiece by the distance required for sparking, known as the *sparking gap*. Should the electrode contact the workpiece, sparking will cease and no material will be removed. There are some EDM machines that do allow the electrode to contact the workpiece. These machines are used primarily for removing broken taps and drills and are not considered die-sinker or wire-cut types of EDM machines.

Another basic fundamental of the process is that only one spark occurs at any instant. Sparking occurs in a frequency range from 2,000 to 500,000 sparks per second causing it to appear that many sparks are occurring simultaneously. In normal EDM, the sparks move from one point on the electrode to another as sparking takes place. Figure 1-2 illustrates that each spark occurs between the closest points of the electrode and the workpiece.

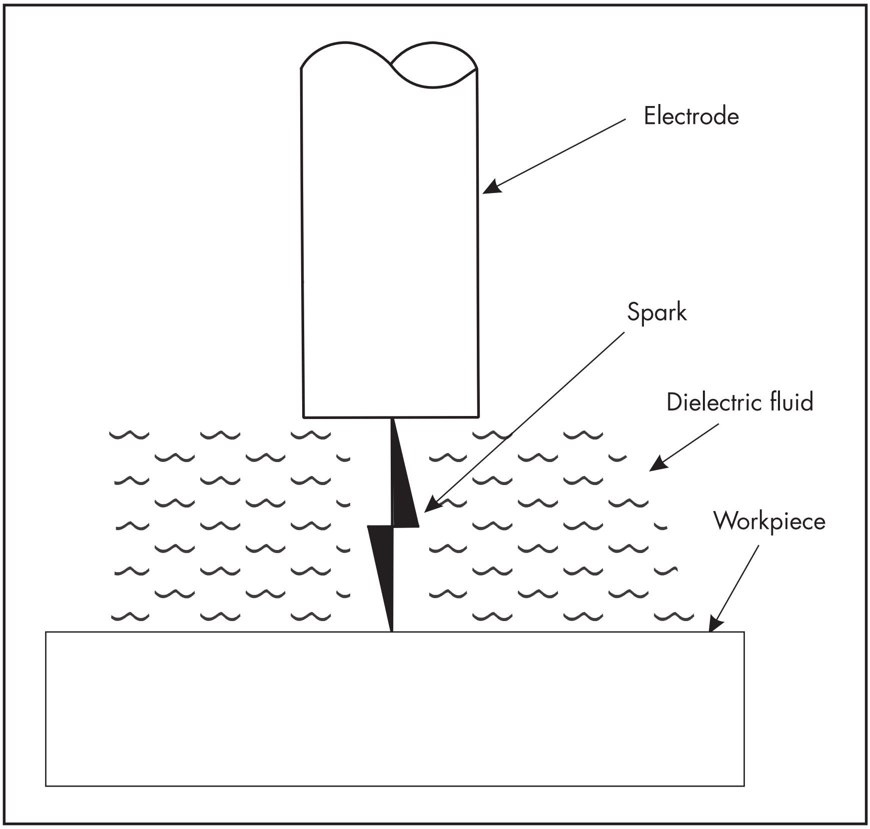


Figure 1-1. Basic components of EDM.

The spark removes material from both the electrode and workpiece, which increases the distance between the electrode and the workpiece at that point. This causes the next spark to occur at the next-closest points between the electrode and workpiece. Figure 1-3 illustrates how this works.

EDM is a *thermal process*; material is removed by heat. Heat is introduced by the flow of electricity between the electrode and workpiece in the form of a spark. Material at the closest points between the electrode and workpiece, where the spark originates and terminates, are heated to the point where the material vaporizes.

While the electrode and workpiece should never feel more than warm to the touch during EDM, the area where each spark occurs is very hot. The area heated by each spark is very small so the dielectric

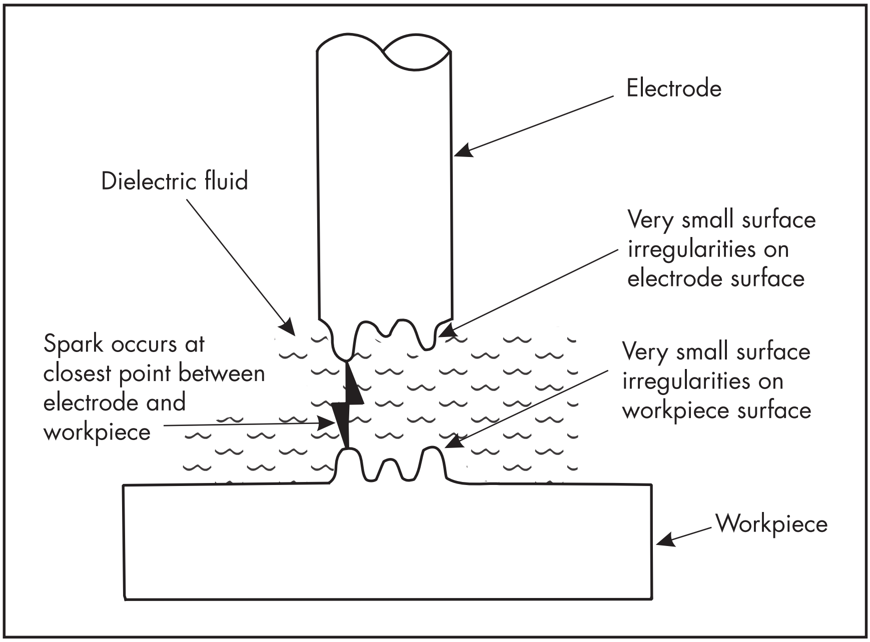


Figure 1-2. Sparking occurs at closest points between the electrode and workpiece.

fluid quickly cools the vaporized material and the electrode and workpiece surfaces. However, it is possible for metallurgical changes to occur from the spark heating the workpiece surface.

A dielectric material is required to maintain the sparking gap between the electrode and workpiece. This dielectric material is normally a fluid. Die-sinker type EDM machines usually use hydrocarbon oil, while wire-cut EDM machines normally use deionized water.

The main characteristic of dielectric fluid is that it is an electrical insulator until enough electrical voltage is applied to cause it to change into an electrical conductor. The dielectric fluids used for EDM machining are able to remain electrical insulators except at the closest points between the electrode and the workpiece. At these points, sparking voltage causes the dielectric fluid to change from an insulator to a conductor and the spark occurs. The time at which the fluid changes into an electrical conductor is known as the *ionization point*. When the spark is turned off, the dielectric fluid deionizes and the fluid returns to being an electrical insulator. This change of the dielectric fluid from

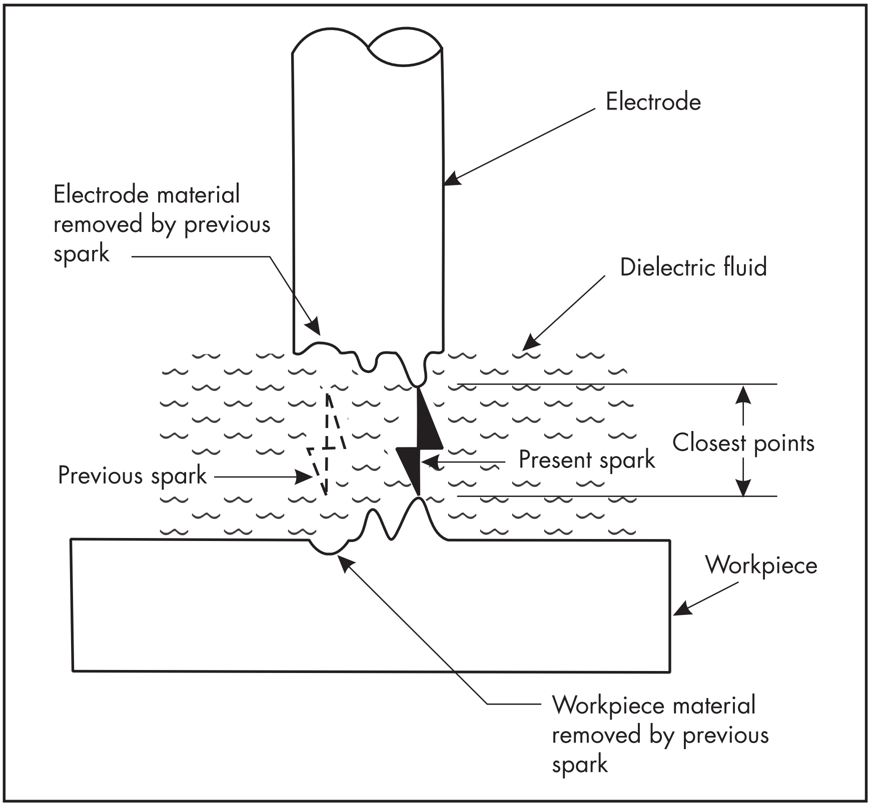


Figure 1-3. Next spark occurs at closest points between electrode and workpiece.

an insulator to a conductor, and then back to an insulator, happens for each spark. Figure 1-4 illustrates the EDM spark occurring within an ionized column of the dielectric fluid.

Dielectric fluid used in EDM machines provides important functions in the EDM process. These are:

- controlling the sparking-gap spacing between the electrode and workpiece;
- cooling the heated material to form the EDM chip; and
- removing EDM chips from the sparking area.

As each spark occurs, a small amount of the electrode and workpiece material is vaporized. The vaporized material is positioned in the spark-

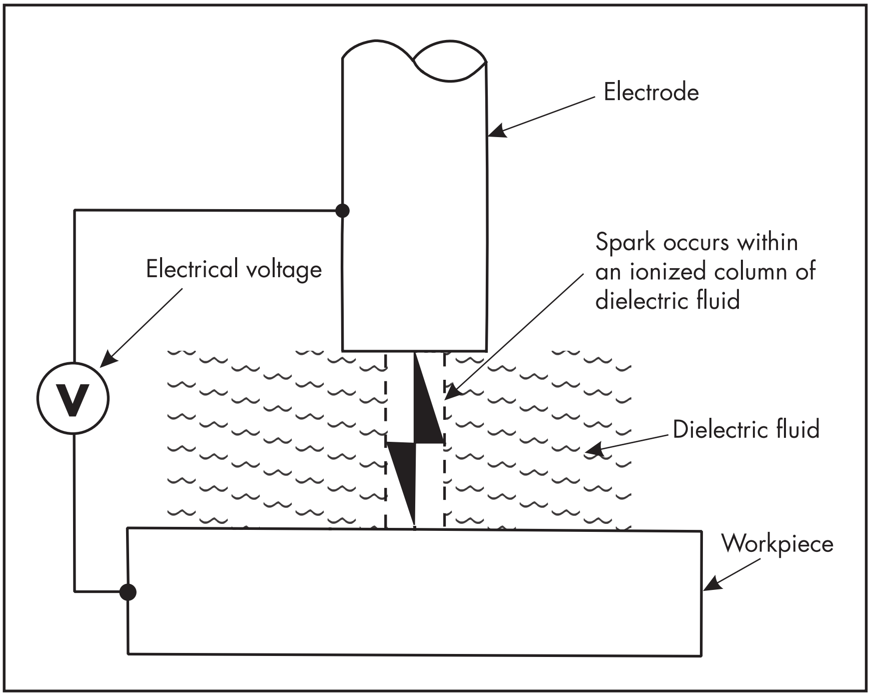


Figure 1-4. Spark occurs within a column of ionized dielectric fluid.

ing gap between the electrode and workpiece in what can be described as a cloud. When the spark is turned off, the vaporized cloud solidifies. Each spark then produces an EDM chip or a very tiny hollow sphere of material made up of the electrode and workpiece material. Figures 1-5, 1-6, and 1-7 illustrate the spark producing the vapor cloud, the cloud in suspension, and the vaporized cloud being cooled and forming into an EDM chip.

For efficient machining, the EDM chip must be removed from the sparking area. Removal of this chip is accomplished by flowing dielectric fluid through the sparking gap.

EDM is sometimes referred to as *spark machining, arc machining,* or even *burning*. Spark machining and arc machining are accurate descriptions of the process since they indicate precision and control of the sparks used in the machining process. Burning is not an apt description as it implies a process where combustion takes place. The term "burning" also gives the impression that fire is involved. EDM requires

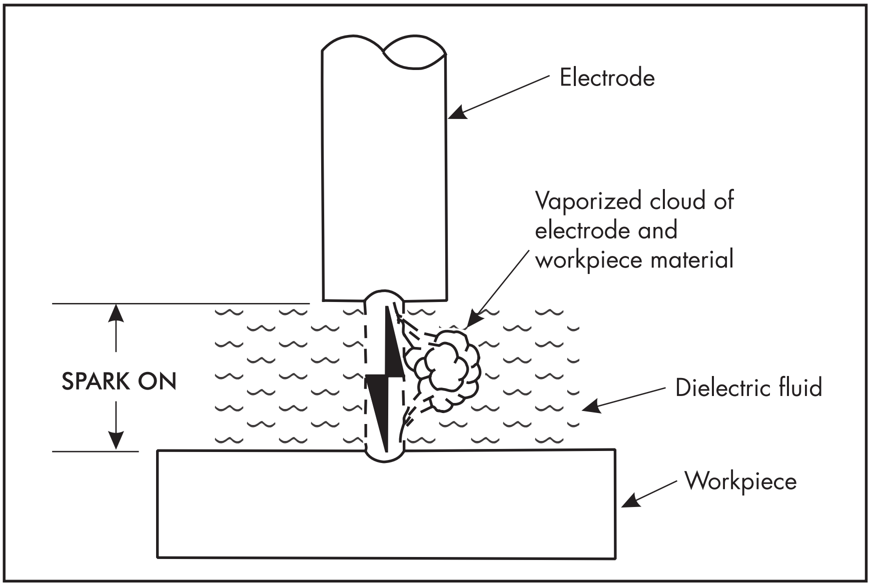


Figure 1-5. Spark ON: electrode and workpiece material vaporized.

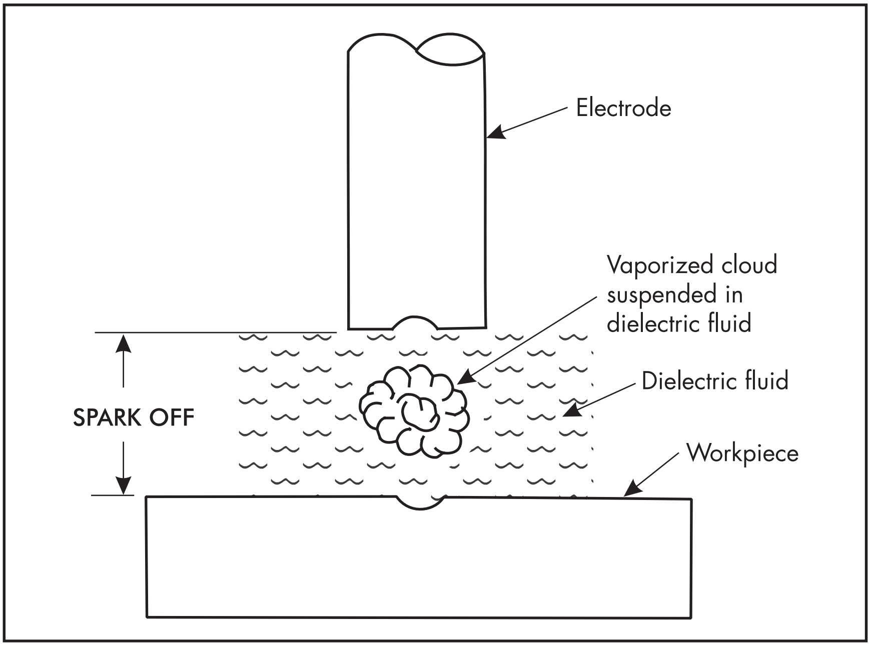


Figure 1-6. Spark OFF: vaporized cloud suspended in dielectric fluid.

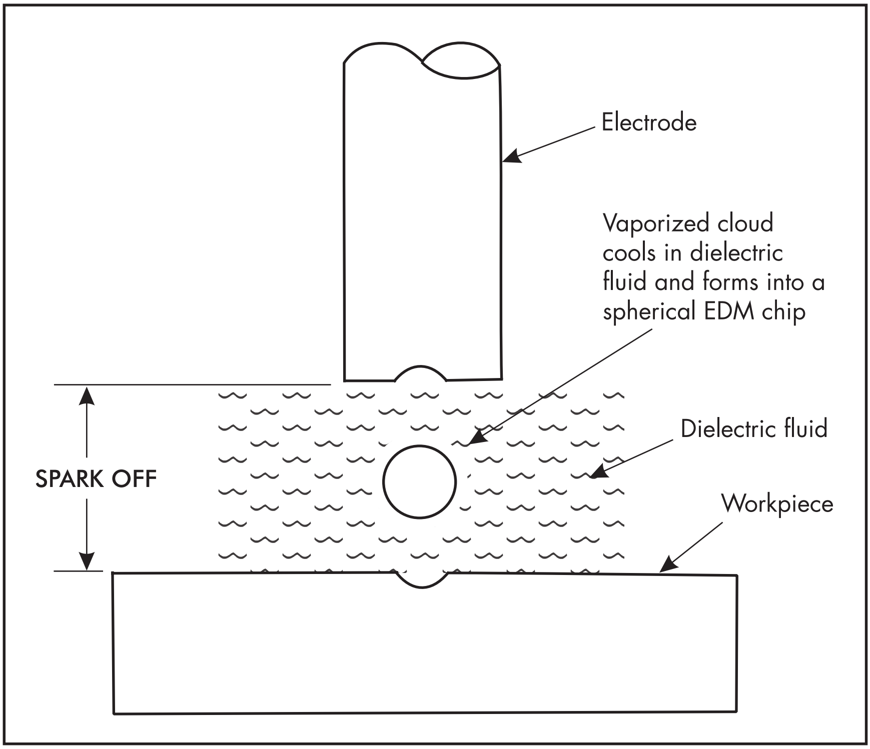


Figure 1-7. Spark-OFF: vaporized cloud solidifies to form EDM chip.

a very precise flow of electricity in the form of a spark; fire is not an accurate or acceptable description of the EDM machining process.

DEVELOPMENT OF EDM

This section will cover the early development stages of both the die-sinker and wire-cut methods of EDM.

DIE-SINKER EDM

EDM originated from the need to perform machining operations on difficult-to-machine metals. The process was developed almost simultaneously in the USSR and the USA at the beginning of World War II.

EDM Development in the USSR

In 1941, the USSR was involved in World War II and critical materials needed to be conserved. Tungsten was widely used as electrical contact material for automotive-engine, distributor-breaker points. As pitting occurred, the engines required maintenance. It was probable that military vehicles would not be in service when needed. Even the replacement of the breaker points caused valuable tungsten to be discarded. To address this issue, the government assigned Moscow University Professors Dr. Boris Lazarenko and Dr. Natalya Lazarenko at the All Union Electro Technical Institute to investigate whether the life of the components could be extended by suppressing sparking between the breaker points.

As part of their experimentation, the Lazarenkos immersed the breaker points in oil. They observed that, while the oil did not eliminate the sparking, it did create more uniform and predictable sparking and pitting, as compared to operating the breaker points in air. Figure 1-8 illustrates the immersion of the contacts.

The Lazarenkos' experiment was not successful because it did not develop a means for extending the life of the automotive breaker points due to sparking. But the Lazarenkos, being very observant engineers, decided to investigate the possibility of controlled-metal removal through the use of sparks. Their interest intensified as they observed that sparks could be used to remove material from tungsten. In 1943, the Lazarenkos developed a spark-machining process with an electrical circuit that used many of the same components as the automobile ignition system. This process became one of the standard EDM systems in use throughout the world. Since the Lazarenko EDM system used resistors and capacitors, it became known as a *resistor-capacitor (R-C) circuit* for EDM. Figure 1-9 illustrates this system.

The Lazarenkos continued to develop their machining system, eventually designing an electrode-servo system that automatically maintained the electrode-to-workpiece sparking gap during the EDM machining cycle.

Many Lazarenko EDM machines were produced during the World War II-years, which allowed practical machining of difficult-to-machine metals, such as tungsten and tungsten carbide. When the process of machining with sparks gained recognition outside the USSR, the

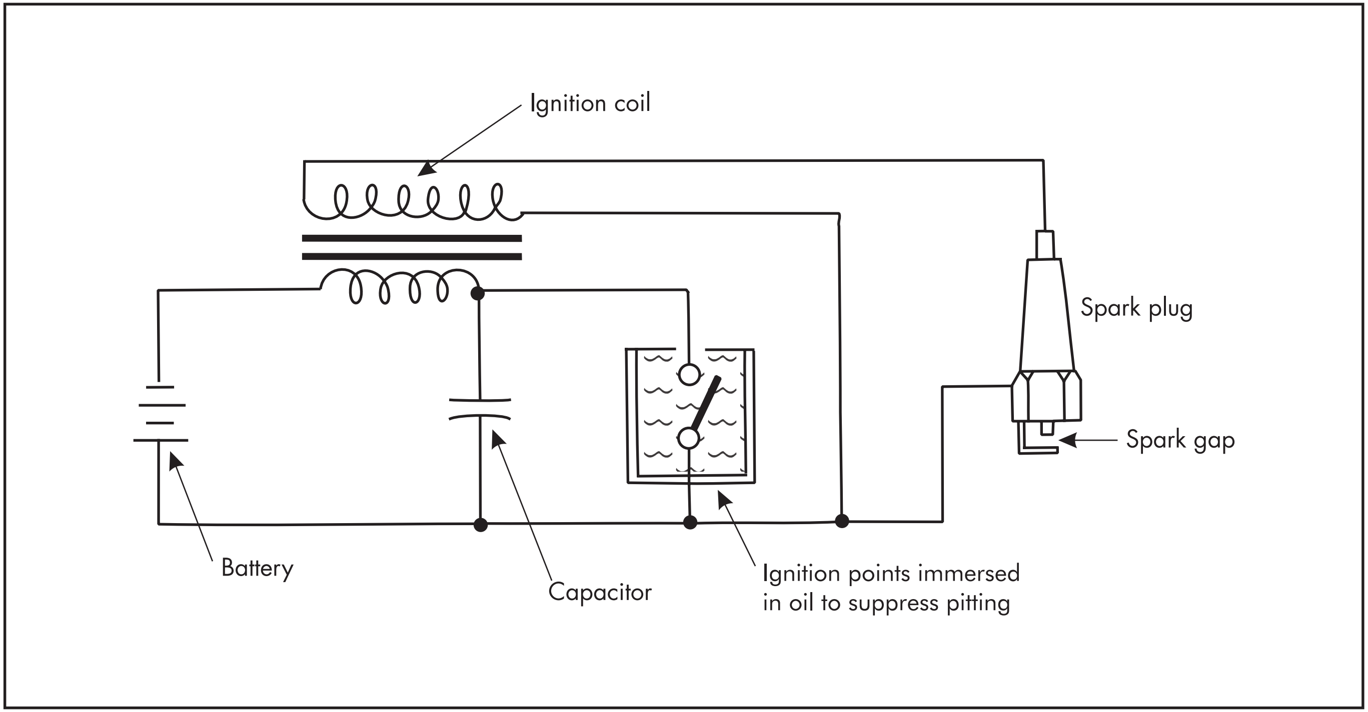


Figure 1-8. Lazarenko experiment with auto-ignition system.

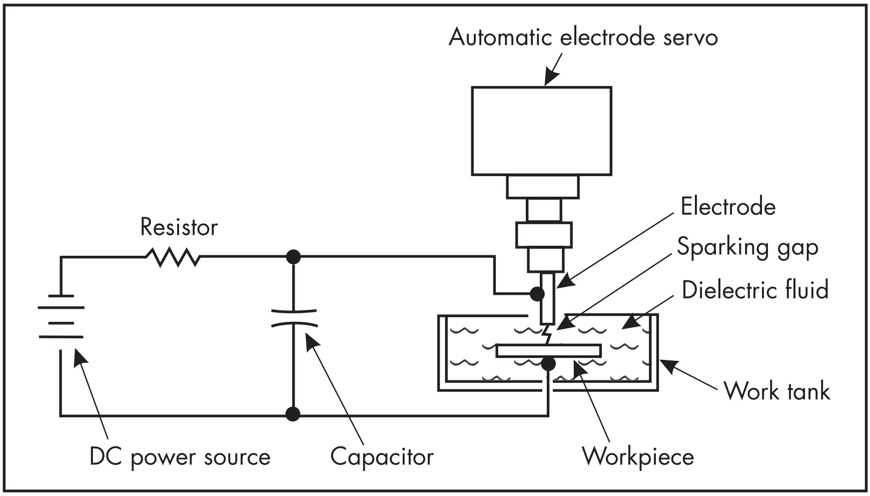


Figure 1-9. Lazarenko resistor-capacitor (R-C) EDM circuit.

Lazarenko EDM system served as the model for most of the EDM machines produced in Europe and Japan.

R-C-type EDM machines are still produced and used around the world. Their use is centered on applications that require a fine surface and the drilling of small, precise orifices.

EDM Development in the USA

At nearly the same time as when the Lazarenkos were beginning to experiment with spark machining, and without knowledge of what was taking place in the USSR, a company in the USA discovered a need for a machine to remove broken taps and drills. Their products included hydraulic valves with aluminum bodies. During the production process, many drills and taps were being broken within the valve body. The parts, used in aircraft applications, were costly. So, three employees—Harold Stark, Victor Harding, and Jack Beaver—were assigned a project to find a way to remove the broken taps and drills and salvage the parts.

Timing of the US project directly corresponded to that of the one undertaken by the Lazarenkos in the USSR. But the two groups' experimental approaches greatly differed. Harding, an electrical engineer, came up with the idea of using sparks to erode the taps and drills

from the valve bodies. Originally, an electric-etching tool was used to produce the sparks. The etching-tool electrode was placed on the broken tap or drill and then withdrawn. As the electrode was lifted from the tap or drill, a spark occurred. The spark melted a small portion of metal, allowing the broken tap or drill to be removed in pieces. The procedure worked, but was much too slow to be of any practical value in salvaging the hydraulic-valve bodies. To improve the speed of the process, they built a more powerful sparking version of the etching tool. Figure 1-10 illustrates this design.

The higher-sparking power unit was able to remove the taps and drills, but it produced hot molten material that had to be removed from the sparking area. Removing the molten material with compressed air produced only limited success. This approach used very large quantities of compressed air and left considerable metal in the sparking area. After considerable experimentation, it was determined that water could be used as a coolant and machining time was reduced to a point where the system was practical.

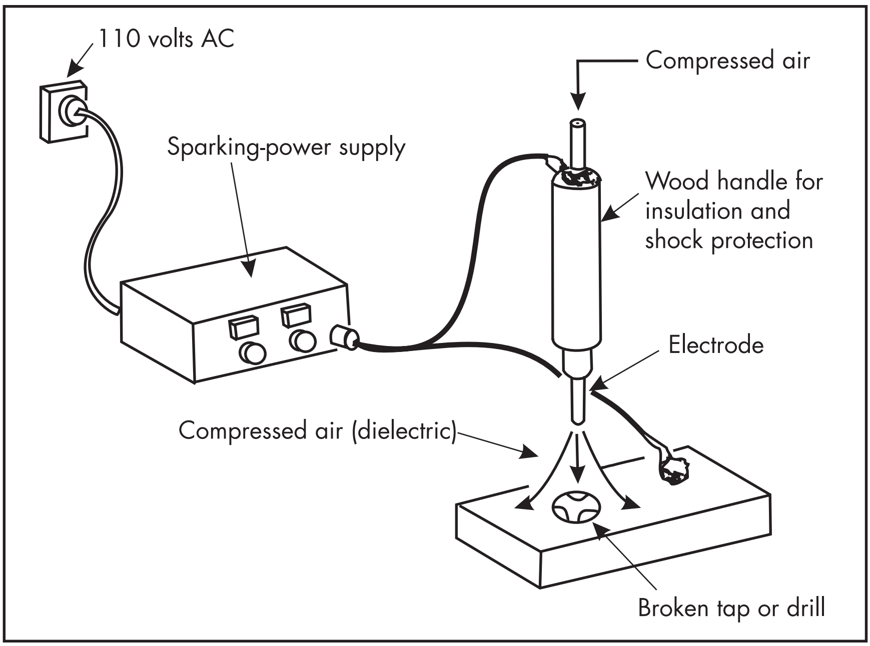


Figure 1-10. Stark, Harding, and Beaver: early EDM experiment.

To make it even more efficient, Stark, Harding, and Beaver were requested to automate the process. The machine they developed consisted of a movable quill with an electrode attached. The quill was free to move in an up-and-down direction. Above the quill was an electromagnet that, when energized, would pull the quill up and away from the workpiece. When the electricity was off, gravity caused the quill to slide back down and into contact with the workpiece surface. Figure 1-11 illustrates the quill in the down position.

As the machine was manually switched on, electricity flowed through the electromagnet, the electrode, and the workpiece. This caused the electromagnet to be energized and the quill was pulled upward. During the upward movement, the electrode separated from the workpiece, producing a spark. (Figure 1-12 illustrates this movement.) As the electrode separated from the workpiece, the open distance acted like an automatic switch turning off the electricity. Without electricity, the electromagnet lost its magnetism and the quill with the electrode dropped down to touch the workpiece. This caused the electricity to start flowing again and another cycle was in progress. Many of these machines were built and used during the World War II era in the USA.

Stark, Harding and Beaver eventually left the valve company and were allowed to patent their system. Their work became the basis for the vacuum-tube EDM machine and an electronic-circuit servo system that automatically provided the proper electrode-to-workpiece spacing for sparking, without the electrode contacting the workpiece. The vacuum tube made it possible to increase spark frequency from 60 times per second to thousands of sparks per second. Figure 1-13 illustrates a simple diagram of the vacuum-tube, EDM-sparking circuit.

WIRE-CUT EDM

It is difficult to establish a time when wire-cut EDM came into being. The development of the process took place over a period of approximately 10 years ranging from the early 60s to the early 70s. In all probability, the developers and users of the die-sinker EDM machines started imagining how the machined electrodes could be replaced with something less labor-intensive and costly. In trying to solve the problem, they may have reasoned that a stationary wire could serve as an electrode, but spark erosion on the electrode surface would weaken

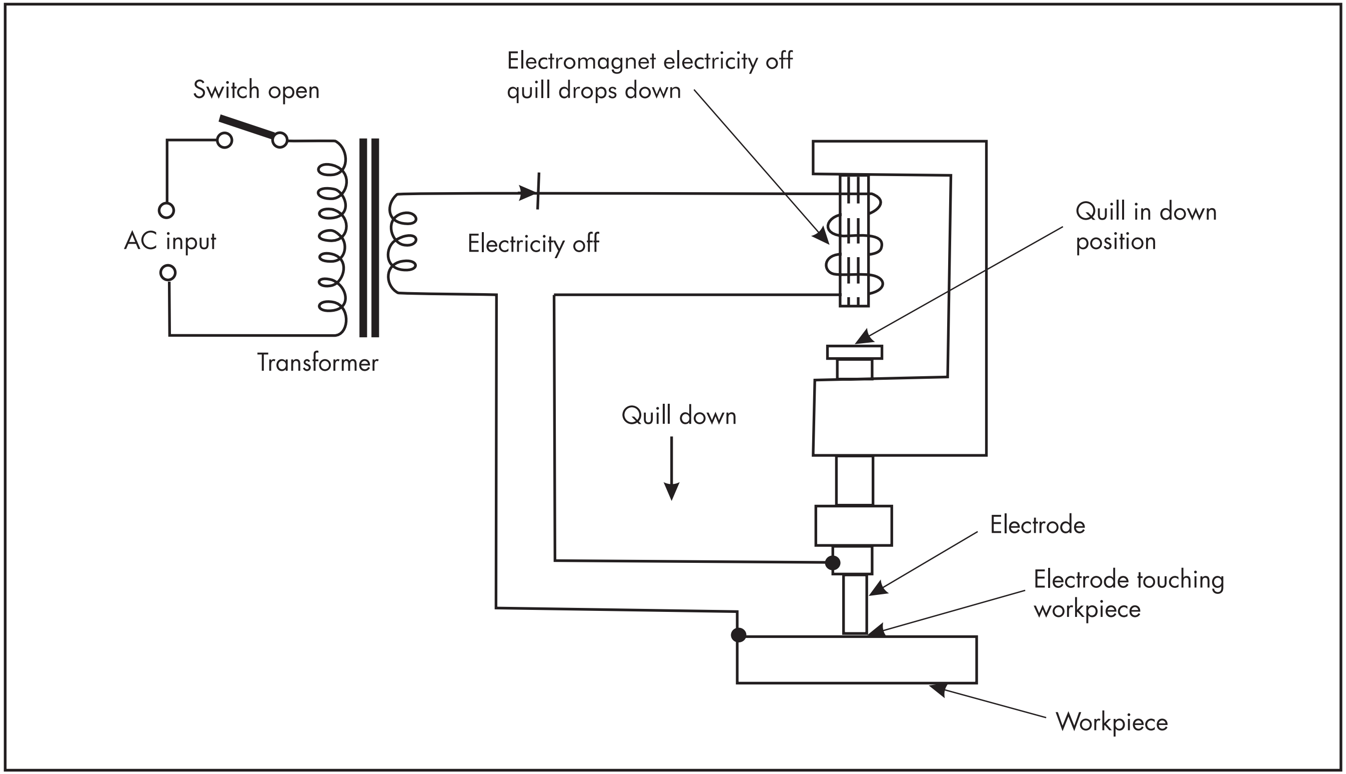


Figure 1-11. Electrode touches workpiece with electricity off.

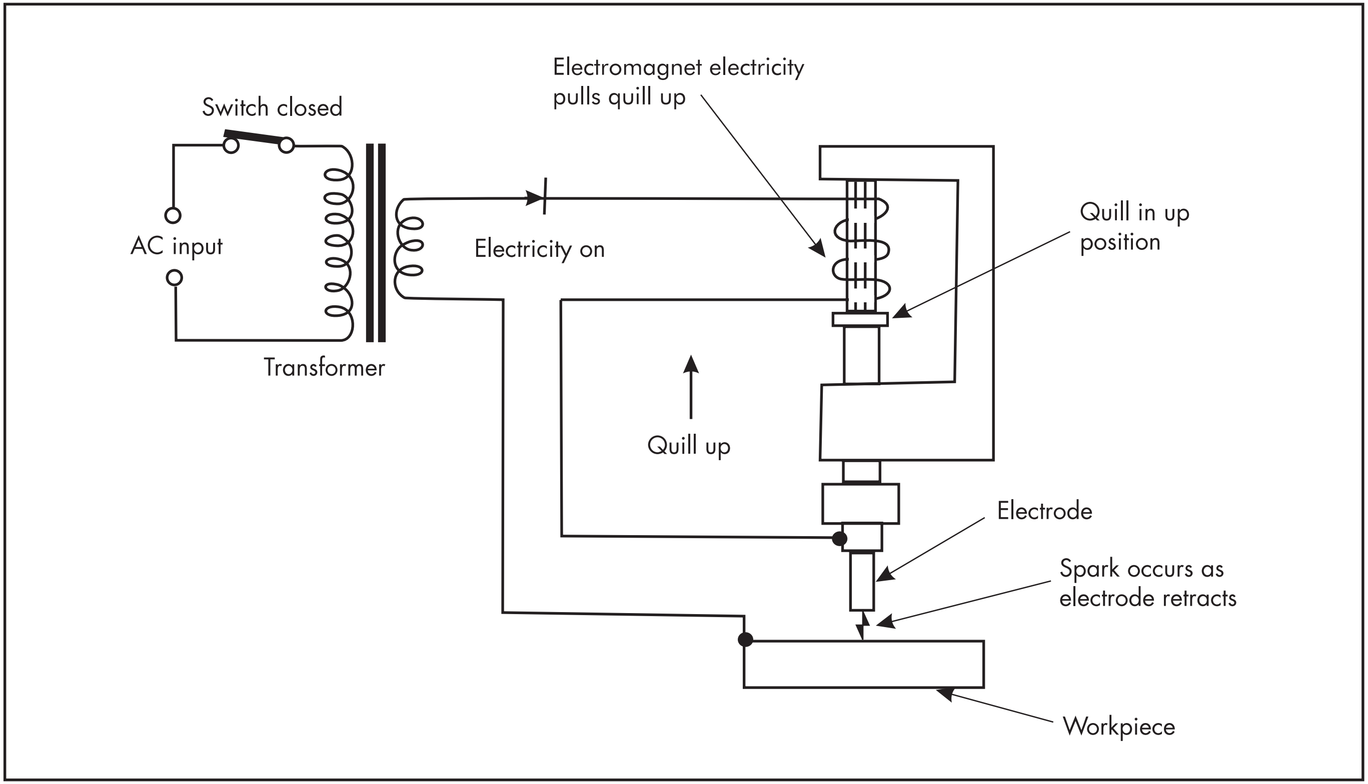


Figure 1-12. Spark occurs as electrode automatically retracts.

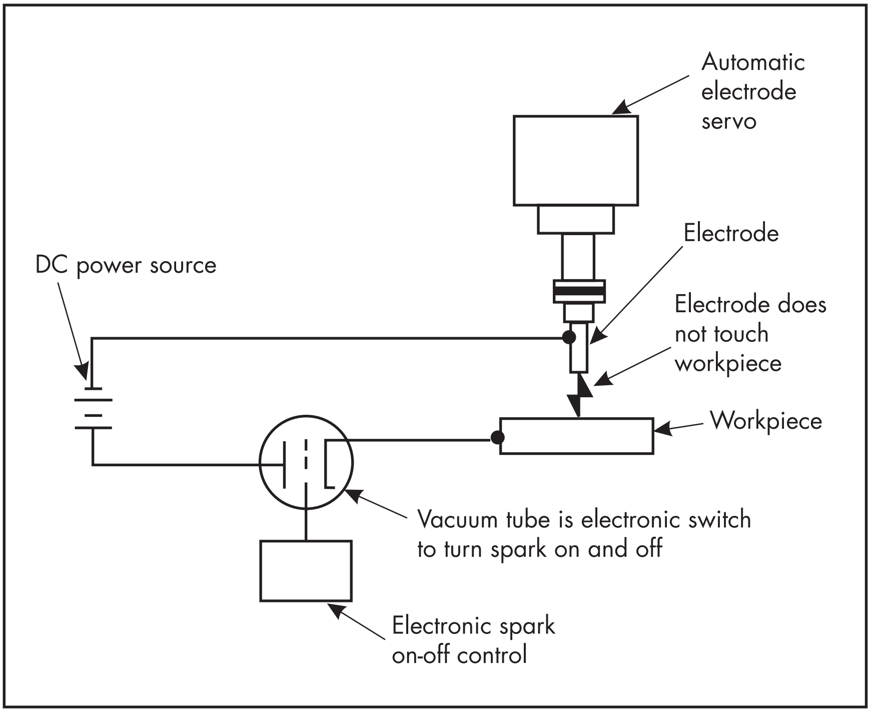


Figure 1-13. Electronic EDM system developed by Stark, Harding, and Beaver.

the wire to the breaking point. However, a wire that continuously traveled past the surface being machined would solve the wire breakage problem.

The first major event in the evolution of wire-cut EDM was numerical control (NC). Accurate axis positioning was achieved by having the EDM machines read perforated tape to control operational movements. These tapes became very long and most of the smaller machine shops did not have programming capabilities. In the 1960s, some of the larger die-making machine shops that had punched-tape programming facilities converted their conventional vertical milling machines into wire-cut EDM machines. These machines used power supplies from the die-sinker type of EDM machines. The EDM rate on these machines was reported to be approximately .750 in. (19.05 mm) per hour when machining .250-in. (6.35-mm) thick, hardened die steel. This machining rate would be unacceptably slow if compared to later wire-cut machines.

In 1967, a wire-cut EDM machine produced in the USSR was displayed at a machine exposition in Montreal, Quebec, Canada. This machine featured numerical control with positioning by means of stepping motors. Machining accuracy was .0008 in. (0.020 mm). The time required to produce a cut of 5 in. (127 mm) in length through 0.5-in. (12.7 mm) steel was three hours.

A portion of an engineering report describing the USSR wire-cut machine included the following comment: "This is a beautifully engineered piece of equipment and will produce through-hole and two-dimensional contours to a commercial accuracy with a good surface finish in a reasonable time with no electrode required. However, it is limited in usefulness for general-purpose work because of the requirements for NC and tape programming. This is a current market restriction, which lessens every day as NC continues to grow."

The USSR wire-cut EDM machine was probably the first commercially available unit to be marketed.

During the 1960s, another noteworthy event took place. A group headed by David H. Dulebohn developed an optical-line following system. This system required an accurate master drawing of the shape to be machined. The optical-line follower traced over the drawing, transferring it to the *X-Y* positioning system of a machine tool. Many of these systems were produced and adapted to milling machines and jig grinders.

In using the optical-line follower system, the master drawing determined the final accuracy of the shape being machined. It was determined that greater drawing accuracy would be possible through the use of a computer-generated drawing. Based on this knowledge, software and hardware were developed to produce a computer-numerical-controlled (CNC) system for plotting the master drawing.

During the time of development of the program for the CNC-plotter system, wire-cut-EDM machining came to the attention of the Dulebohn group. They reasoned that the newly developed CNC-drawing-plotter system could be used, along with the optical-line follower mechanism, to automatically control the shape to be machined by the wire-cut EDM process. In 1974, a wire-cut EDM machine controlled by the optical-line following system was introduced.

Eventually, the optical-line follower, wire-cut EDM machine concept was set aside. The Dulebohn group found that the same computer program used to control the CNC-plotting system also could

control the machine itself. This eliminated the need for the master drawing and the optical-line following mechanism. Based on this engineering approach, a computer-numerical-controlled, wire-cut machine was developed in 1976.

Many things happened in a fairly short period of time, starting in the early 1970s, which made wire-cut EDM a practical machining system. Numerical control was replaced by computer-numerical control, eliminating the need for punched tape. Ball screws became available, which allowed for an anti-backlash, anti-friction means of table-axis movement. Anti-friction, pre-loaded table ways became available, which reduced stick friction in the table movement. Servo motors with encoder and tachometer-feedback capability made table-axis feed and position control practical. These items were developed for the more conventional chip-making machines, but their availability was perfectly timed for computer-numerical-controlled, wire-cut EDM. With all of the hardware available for the wire-cut EDM system in place, the final, and possibly most important, item was developed—wire-cut, process-computer software. In its original form, the software was difficult to use. But with time, the programming software was refined and simplified to the point that it was acceptable even to shops without CNC programming specialists. Simplification of the programming brought about nearly universal acceptance of the wire-cut EDM process. As a result, wire-cut EDM has become the EDM process of first choice for through-hole applications, such as stamping and extrusion dies.

COMPARISON OF DIE-SINKER AND WIRE-CUT MACHINES

Both die-sinker and wire-cut EDM machines use sparks to remove electrically conductive material. But while both types are electrical discharge machines, there are differences in their use and operation. Some of these differences are listed in the following text.

Dielectric fluid:

- die-sinker EDM machines use hydrocarbon oil and submerse the workpiece and spark in the fluid; and
- wire-cut EDM machines normally use deionized water and contain only the sparking area in the fluid.

Applications:

- die-sinker EDM machines are normally used for producing three-dimensional shapes;
- these shapes utilize either cavity-type machining or through-hole machining; and
- wire-cut EDM machines are always used for through-hole machining, since the electrode wire must pass through the workpiece being machined.

Die-sinker and wire-cut sparking:

- die-sinker machines produce sparks that occur between the electrode end and the workpiece. Figure 1-14 illustrates this sparking; and
- wire-cut machines produce sparks that occur between the electrode-side surface and the workpiece. Figure 1-15 illustrates this sparking.

Sparking area:

- die-sinker sparking occurs across the end surface and from the corners of the electrode (see Figure 1-16). Spark length is set by the machine controls. Sparks occur from the electrode corners, producing a clearance between the electrode corner and the sidewalls of the workpiece. The machined clearance between the electrode corner and the workpiece sidewall is the spark overcut. The electrode-end sparking surface, plus the sidewall-overcut distance, is the sparking area; and
- wire-cut sparking occurs between the side and machined surfaces of the workpiece (see Figure 1-17). Spark length is set by the machine controls. The sparking area consists of only the front 180° of the electrode diameter as it progresses into the cut. A clearance equal to the spark length is machined on each side of the wire electrode. This side clearance is the *spark overcut*. The total width of the machined opening consists of the electrode diameter, plus two times the spark length. The total width of the machined opening is the *kerf*.

Both die-sinker and wire-cut machines use sparking to remove electrically conductive material. However, they do not normally use the same kind of dielectric fluids or electrodes. While the machines are

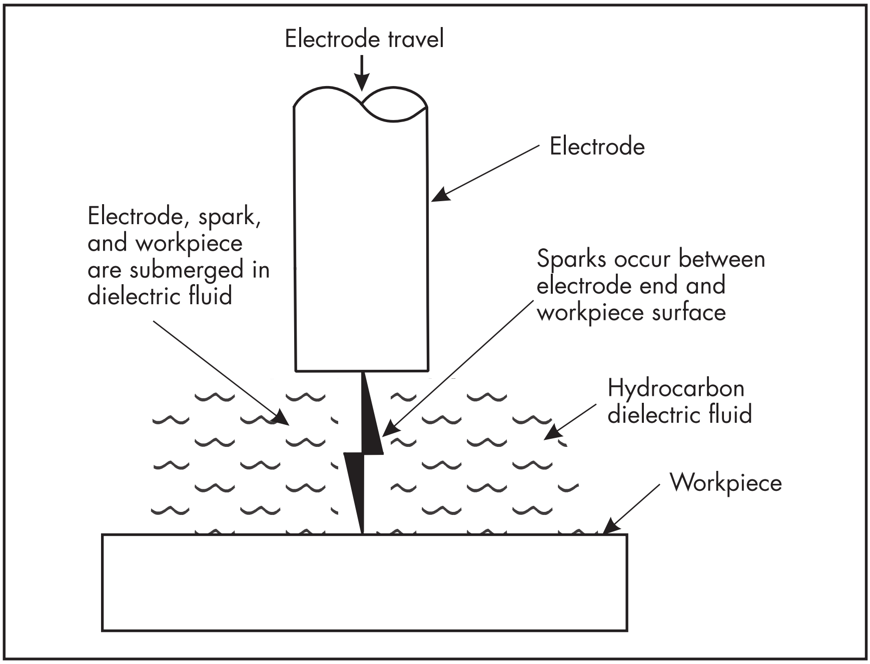


Figure 1-14. Die-sinker sparking from electrode end.

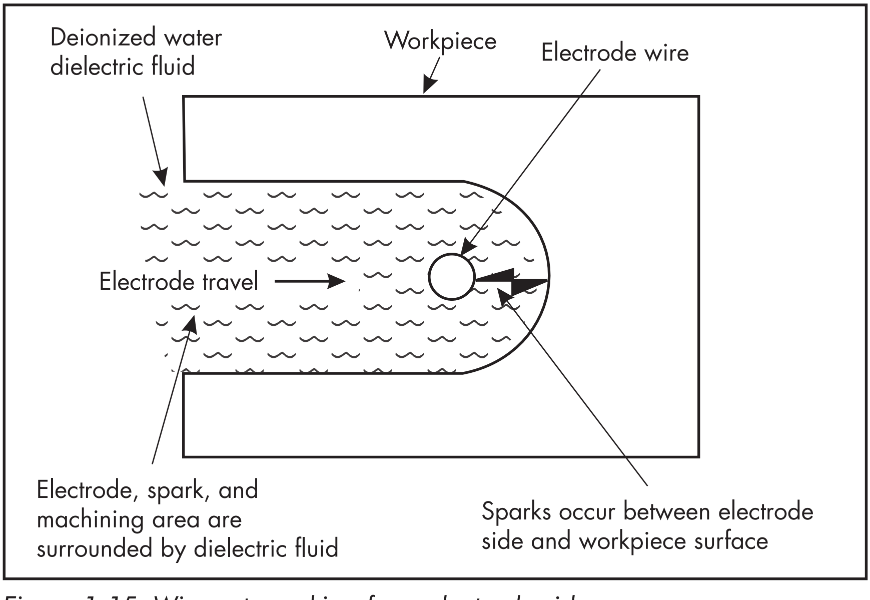


Figure 1-15. Wire-cut sparking from electrode side.

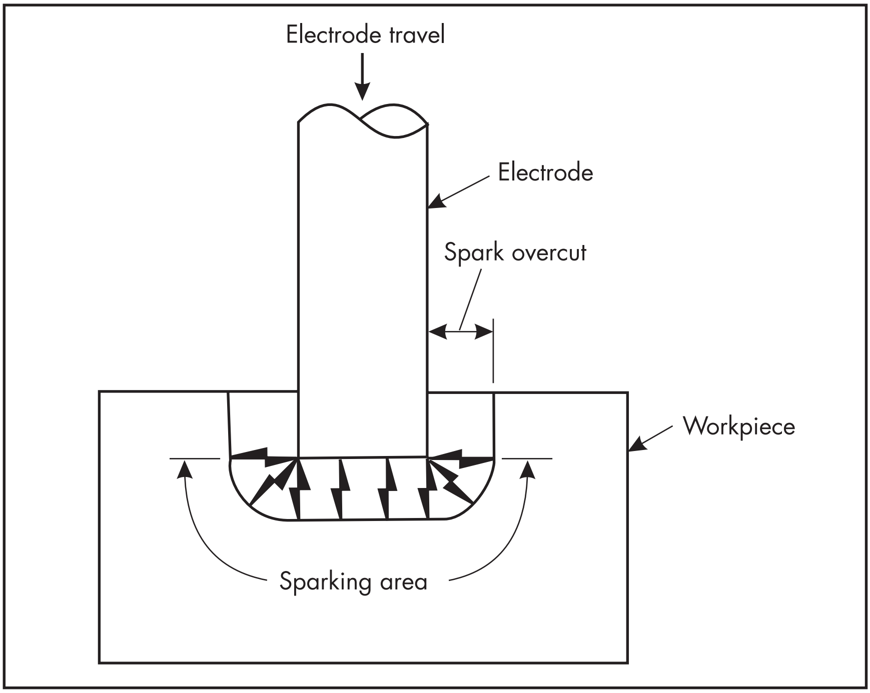


Figure 1-16. Die-sinker sparking area.

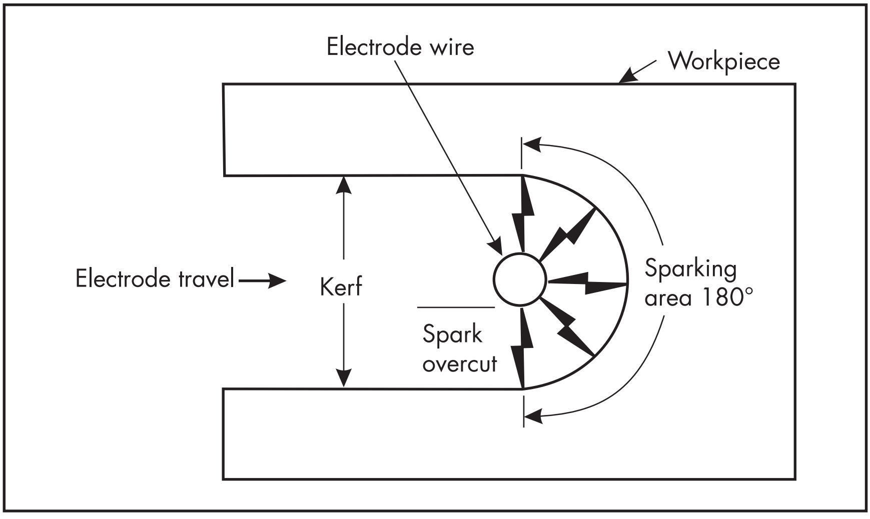


Figure 1-17. Wire-cut sparking area.

similar, they are not identical. Operational data and charts, therefore, must be specific for the type of machine being used.

ACCEPTANCE OF THE EDM PROCESS

EDM was not as readily accepted in the US as it was in most other parts of the world. This was primarily because the US did not sustain damage to its industrial factories during World War II. In addition, the US had highly skilled workers trained on existing equipment. EDM required new thinking and an acceptance of using electricity as a method of metal removal. With its industrial base so well established and productive, US industry saw no reason to switch to a new process. As a result, it took some time for EDM to be accepted.

Japan was not so fortunate in the aftermath of World War II. The Japanese industrial base was, for all practical purposes, destroyed. As a result, industry in Japan was very willing to accept EDM. A great deal of research was put into developing EDM machines to suit its needs. One of the leaders in this research and development in Japan was Dr. Kiyoshi Inoue.

European countries also accepted EDM almost from the beginning. Most of the early EDM machines were based on the Lazarenko developments. By the end of World War II, most of the machines sold worldwide were of European manufacture, with the exception of those sold in the USA.

2 The EDM System

This chapter discusses the EDM die-sinker machine structure and machining systems, as well as EDM assemblies and the EDM wire-cut machine tool.

DIE-SINKER MACHINES

An EDM tool consists of components that work together to form a machine structure. In each machine design, there must be ways to move the electrode in relation to the workpiece, and to position them so that machining takes place at the proper location. Figure 2-1 illustrates the basic components of a die-sinker machine tool. The servo head moves the electrode in a vertical direction and maintains proper electrode-to-workpiece distance so that sparking will occur. The workpiece is attached to the table surface and the *X*-*Y* table is manually positioned so that the machining operation will be accomplished at the correct location.

There are different structures used in designing die-sinker machines. Figure 2-2 illustrates the movable, *X*-*Y* table, fixed-head design. This type of machine is often referred to as a *C-frame* style, due to the shape of the machine when viewed from the side.

Another die-sinker design incorporates a fixed table and a movable servo head. This type of die-sinker design is known as a *bridge*-type style, since the head is supported by a bridge structure over the worktable area. Figure 2-3 illustrates this style of die-sinker machine.

The difference between the C-frame and the bridge-type machines is the *X*-*Y*-positioning, movement location. The C-frame style positions the workpiece and the bridge style positions the electrode.

When evaluating die-sinker machines, there are some machine-style points to consider.

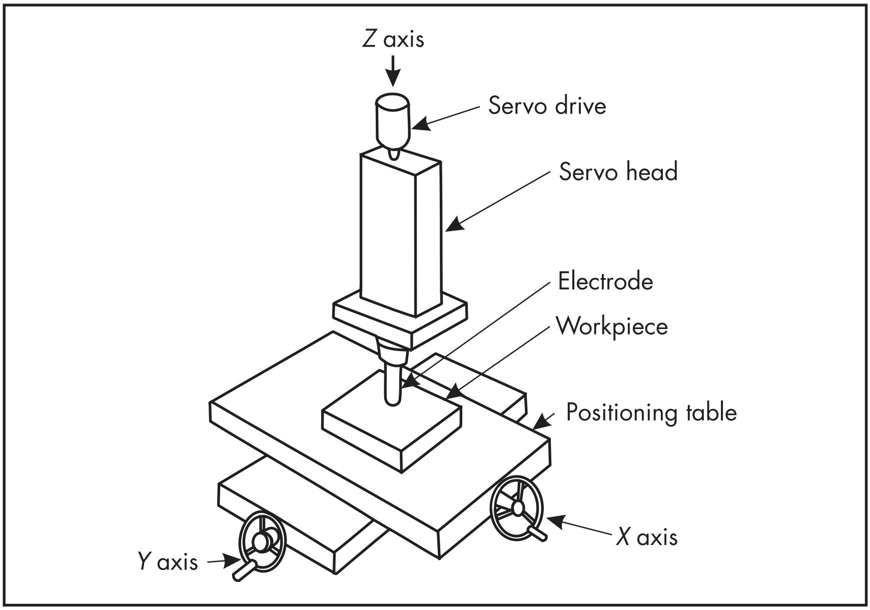


Figure 2-1. Basic die-sinker-EDM machine.

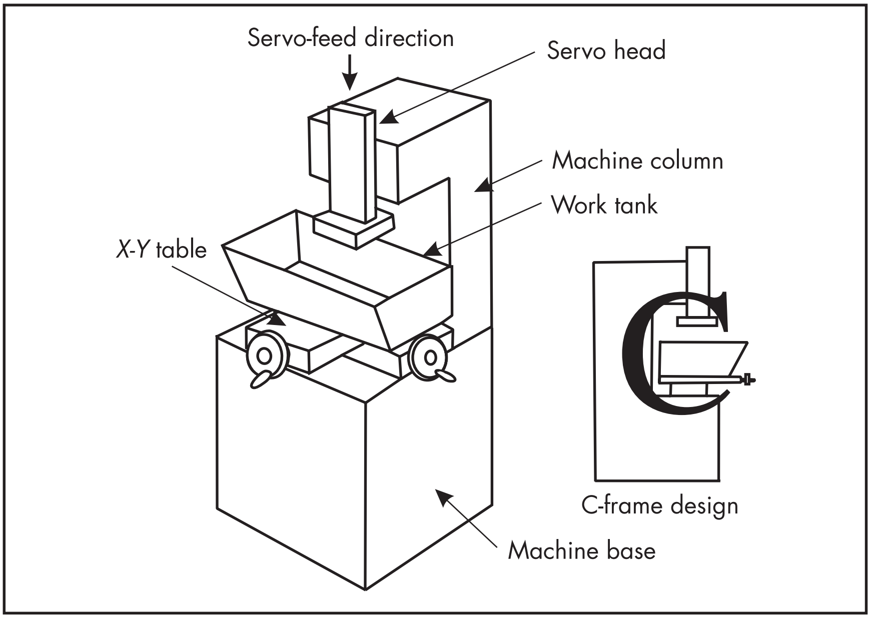


Figure 2-2. C-frame, die-sinker machine.

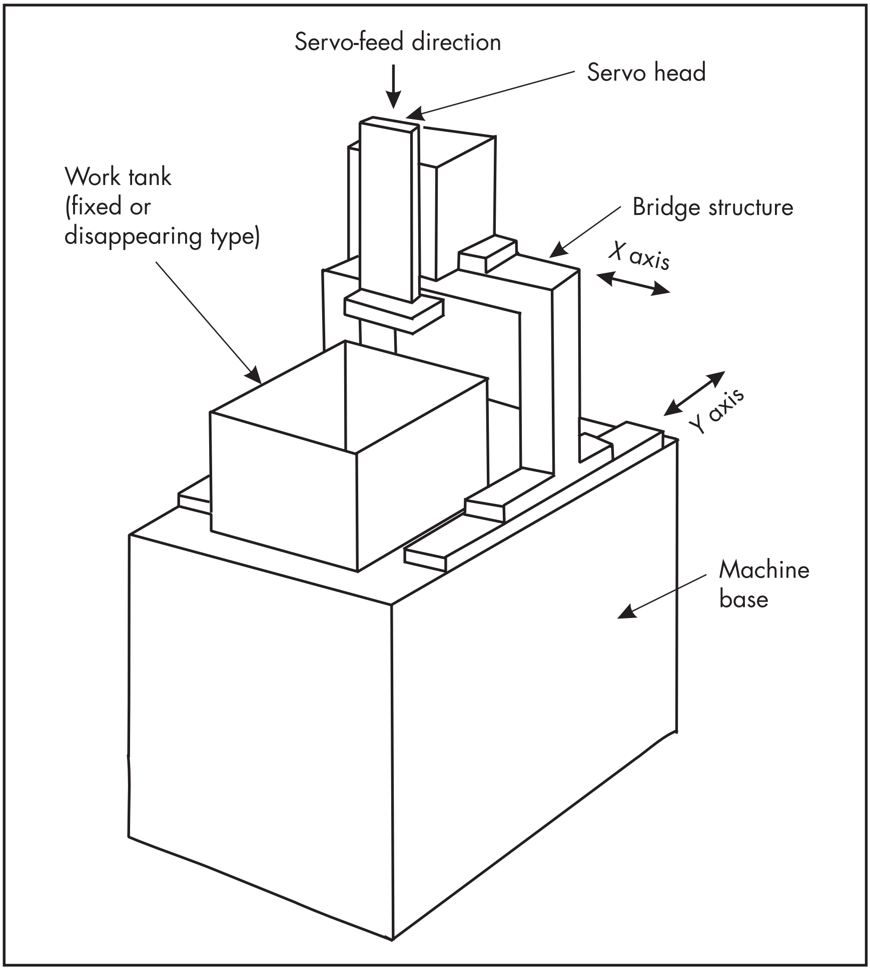


Figure 2-3. Bridge-style, die-sinker machine.

The C-frame style, with the fixed-position servo head, and movable *X-Y* table, is similar in design to other chip-making machines, such as vertical milling machines. The work tank normally includes a removable front that provides access to the machine table for mounting and inspection of the workpiece. The servo head retracts up and away from the table for setup operations.

A bridge-type, die-sinker machine may include a retracting or disappearing work tank on smaller machines. This allows almost complete

accessibility to the worktable surface, since the work tank retracts into the machine base. Die-sinker machines used for very large workpiece applications often have bridge-type construction because it is more practical to position the electrode over the workpiece than to move the workpiece. The bridge construction also allows the machine head to be moved for overhead workpiece loading and unloading.

Each machine must be evaluated to determine the best style for any machining application. The final decision should be based on the experience of those using the equipment, along with the availablility of other support machines at the manufacturing facility.

The primary purpose of the EDM tool is as a structure for supporting and positioning the electrode and workpiece. The structure must be rigid to maintain very precise control over the electrode-to-workpiece sparking gap. Whether the machine is large or small, the sparking gap will always be in an approximate range of .0010–.0040 in. (0.025–0.102 mm). Any movement in the structure that changes the sparking gap will cause erratic operation of the servo system. The servo head must always move accurately over the entire length of travel. Should there be any tilt to the electrode in reference to the direction of servo travel, the machined shape will be distorted. To prevent erratic and inefficient operation of the servo system, the servo slide must not have any side-to-side or front-to-back looseness. It must also be designed with proper lubrication for operating with short-oscillatory movement during extended periods of time. Damage may result to servo-slide components, should the slide become depleted of lubricant.

EDM ASSEMBLIES

In addition to the machine-mechanical unit, the EDM-machine system consists of assemblies and subassemblies that are electrically interconnected as well as plumbing components. Table 2-1 lists the major assemblies that make up an EDM-machine system.

Of the major assemblies required to complete the die-sinker and wire-cut EDM-machine systems, the only comparable item is the power supply. The machine tool, dielectric unit, servo control, and CNC-control assemblies for the two machines have different requirements and must be evaluated separately.

Table 2-1. EDM assemblies.

Die-sinker	Wire-cut
Machine tool	Machine tool
EDM-power supply	EDM-power supply
Dielectric unit	Dielectric unit
Servo control, *Z* axis	Servo control, *X-Y* axes
CNC control (optional)	CNC control (required)

DIE-SINKER-MACHINING SYSTEM

Figure 2-4 illustrates a C-frame-type, die-sinker system. Its three major assemblies are the machine tool, power supply, and dielectric unit. These assemblies are dependent upon one another to such an extent that the EDM system will not function unless all assemblies are operating properly.

The power supply must provide each individual spark to the sparking gap for material removal. It must also monitor the electrical conditions at the sparking gap and direct the machine servo in advancing, retracting, or maintaining the position of the electrode, in reference to the workpiece. The dielectric unit must provide the dielectric fluid to the machine for submersing the workpiece. In addition, the dielectric unit must send fluid to the sparking gap for cooling purposes and to remove the EDM chip. The dielectric unit includes a filtration system for cleaning the dielectric fluid.

The machine tool is the focal point of the die-sinker, EDM-machining system, because the machining takes place at the machine. Subassemblies are included on the machine to protect the machinist, monitor the dielectric fluid, and control the progress of the machining operation. They also control the stability of the servo feed. Figure 2-5 illustrates these subassemblies.

Electrical Control Enclosure

The electrical control enclosure is the central electrical supply of the EDM machine that controls the manual- and automatic-operating systems.

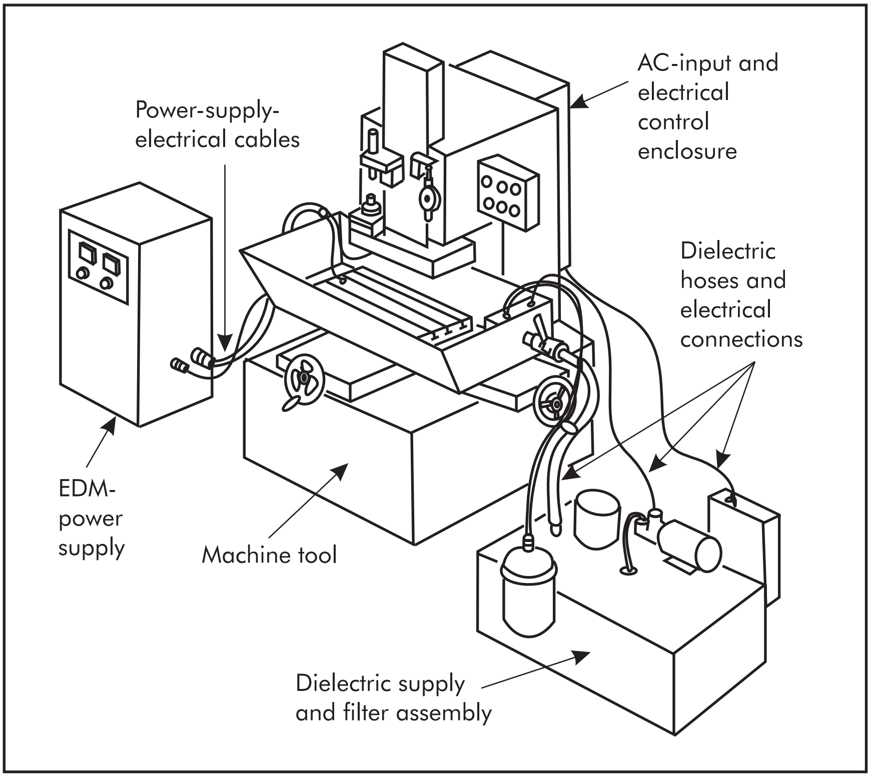


Figure 2-4. Die-sinker major assemblies.

It is recommended that each EDM machine have a single point of AC-power input in the form of an electrical enclosure. As a safety precaution, the enclosure should contain a master electrical power-disconnect switch. When turned OFF, this switch disconnects the AC-input electricity from all of the machine systems. Compliance with all electrical codes is recommended when installing the machine, including proper grounding to prevent a possible shock hazard to personnel.

All AC-input electrical connections must be properly made prior to turning the electrical power ON at the machine. A service representative from the machine manufacturer should oversee and approve electrical connections prior to machine startup. Should this be impossible, electrical power requirements, wire sizes, terminal connections, and voltages to all assemblies should be checked and approved by a competent electrician.

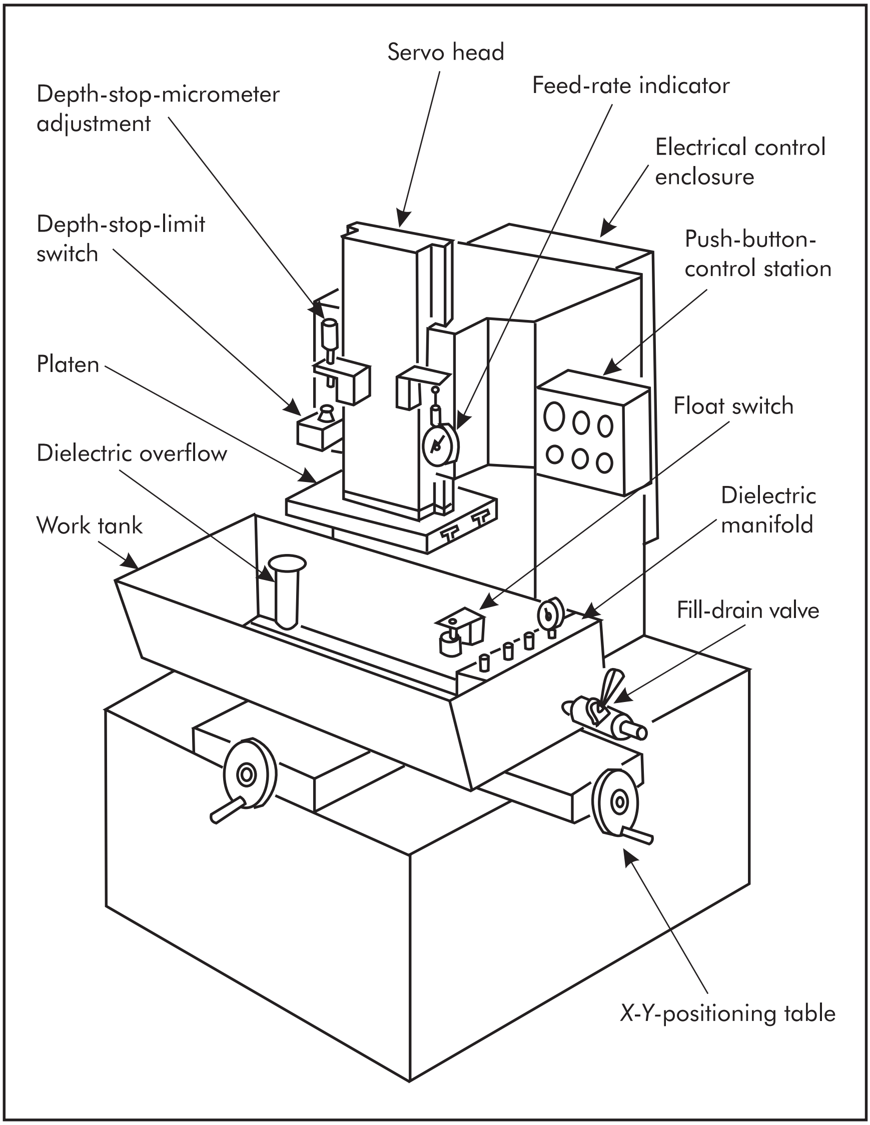


Figure 2-5. Die-sinker-machine subassemblies.

The electrical enclosure includes motor starters, electrical contactors, overload-protection devices, and terminals for connection of the electrical wiring between the EDM-machine tool, power supply, and dielectric unit.

X-Y Positioning

X-Y positioning of the electrode or workpiece is necessary for most applications. This positioning may be accomplished with a table mounted to the machine base, or with a system that moves the entire servo head. Consideration should be given to the positioning accuracy of the system in relationship to the accuracy required for producing the workpiece. Digital readouts may be needed to confirm the precision of movements. A computer numerical control (CNC) machine should be considered when multiple, precise movements are required.

The *X-Y*-positioning table must include a means of attaching the workpiece to the table surface. Examples include T-slots and tapped holes. When tapped holes are used they will collect EDM chips and dielectric-fluid debris, and cleaning them may be a problem. The work-table surface must be square to the servo-head axis of travel. Any inaccuracy in squareness will cause distortion of the workpiece shape.

Work Tank

A work tank that moves with the table is attached to the *X-Y*-positioning table. During machining, it is necessary to fill the sparking gap between the electrode and the workpiece with dielectric fluid to control sparking conditions. The work tank contains the dielectric fluid where the workpiece is submerged.

Often, tanks are fabricated from sheet metal with a removable, or hinged, front door, for ease in setting up the workpiece. In other designs, work tanks retract into the machine base to create an open area around the workpiece and electrode during setup and inspection.

Mounted to (or in) the work tank is a dielectric-fluid manifold. This manifold is connected to the dielectric-fluid-flushing system. It provides attachment points for connecting the electrode or workpiece to the dielectric system. The fluid flushes the EDM chips from the sparking gap. The manifold usually has a valve for setting and a gage for monitoring dielectric-fluid-flushing pressure.

When using a dielectric-fluid assembly that uses a pump for filling the work tank, an overflow standpipe is part of the work-tank/table assembly. This allows dielectric fluid, used for chip removal, to return to the dielectric reservoir. This also maintains the dielectric-fluid level

in the work tank. When pressurized air is used to fill the work tank, the overflow standpipe is not normally required.

Most EDM machines include a monitor to make sure that the dielectric-fluid level in the work tank is not lowered during the EDM cycle. Often, this monitor is a float switch. Should dielectric fluid leak from the work tank, causing the fluid level to lower enough that the sparking is exposed, ignition of the pressurized-atomized fluid is possible. It is imperative that safety instructions, provided by the machine manufacturer, be observed in the use of fluid-level-monitoring devices. Figure 2-6 illustrates one type of float switch for monitoring the dielectric-fluid level in a work tank.

Dielectric-fluid-level monitors should be used with care. In most instances, the monitor will be a mechanically actuated, electric switch. Should the dielectric-fluid level drop below a preset height, the float-switch-electrical contacts will open and cause the machining cycle to stop. The float switch may be mounted to a rod and manually adjusted for fluid height. It is clamped into place in the tank. Different monitor designs exist, but normally all include a way for the machinist to manually adjust the switch for different fluid levels in the work tank.

Use of the float switch prevents the EDM-sparking cycle from starting until its electrical contacts are actuated. In reality, the float-switch design can be improperly used and compromise the safety of the machine and machinist. Any of the following conditions could occur: floats can be held in the "up" position; mechanically positioned float switches can be clamped in a low position; and magnetic-base float switches can be mounted upside down. In all of these instances, the EDM-sparking cycle can be started with low or no dielectric fluid in the work tank. While these conditions may seem to represent design flaws, they actually have a purpose. The machinist must be able to set up the electrode and workpiece for the machining operation. To accomplish this, the electrode may need to be viewed to determine its position relative to the workpiece's top or side surfaces. With sparking ON and the dielectric-fluid level set below the sparking area, the machinist can see sparking between the electrode and workpiece, and then confirm that the position is correct. Most EDM manufacturers train EDM machinists in proper safety procedures for this kind of setup operation. All EDM machinists should know how to reset the float switch after completing setup operations and correct fluid-monitoring levels to maintain the integrity of the unit.

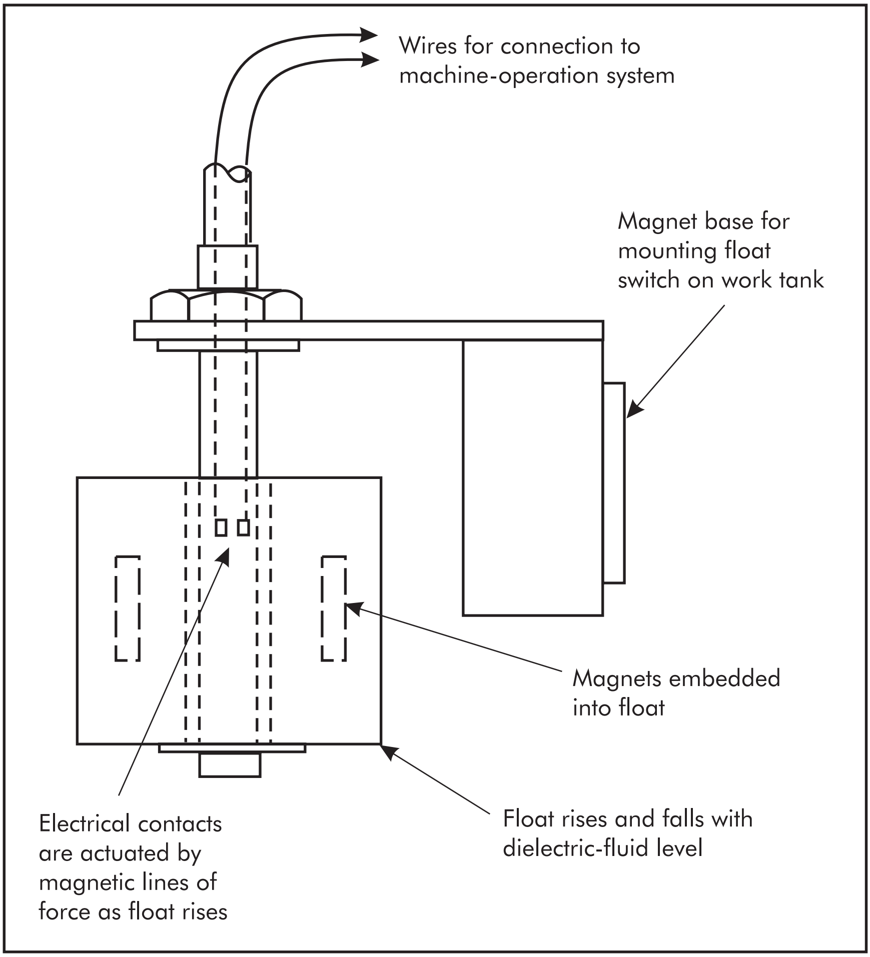


Figure 2-6. Float switch for monitoring fluid level.

The float switch must be properly maintained. Since the mechanism is normally immersed in dielectric fluid, EDM-sparking by-products collect on its moving components. It is possible for debris to overaccumulate and cause the float switch to operate improperly. If the float switch is not positioned properly, or if it becomes inoperative because of sparking debris, the dielectric fluid can drop during the EDM-sparking cycle. If the fluid level drops enough to expose the sparking gap, the hydrocarbon-dielectric fluid could ignite.

When replacement of dielectric-fluid hoses or gasket material is required, materials approved by the machine manufacturer should be used. Dielectric fluid can cause some plastics to harden and break. Gaskets can soften or deteriorate if they are not constructed of an approved material.

Some machine manufacturers offer safety guards that mount to the top of a work tank. These guards are usually provided when the voltage between the electrode and workpiece is considered hazardous. Guarding must be used in accordance with the manufacturer's instructions in order to eliminate hazardous electrical-shock conditions. Whether electrical guarding is provided or not, caution must always be exercised when working around an EDM machine. The possibility of electrical shock is always present during the EDM-sparking cycle. The shock, itself, may not be considered hazardous or cause injury. But, the shock could cause the operating personnel to withdraw quickly from the machine and sustain an injury by contacting sharp or stationary objects.

Pushbutton-control Station

A pushbutton-control station is usually located conveniently on the EDM machine. This control allows manual positioning of the servo head for setup operations and EDM-cycle initiation. A master-stop control allows the sparking power to be turned OFF. It then stops all processes that would cause safety concerns in an emergency.

Machine Column

The machine column prevents flexing during machining, even though it is not an operating component in the EDM system. Since the electrode always remains at sparking distance from the work surface, there is no tool force during machining. It could appear that the strength and rigidity of the machine structure would not be of primary importance. But, this is not the case, for there is considerable force involved in the machining process. This force is derived from the dielectric fluid being forced under pressure through the sparking gap between the electrode and work surfaces. Based on an electrode-end surface of 10 in.^{2} (65 cm^2), and a dielectric-fluid-flushing pressure of 20 psi (138 kPa), a

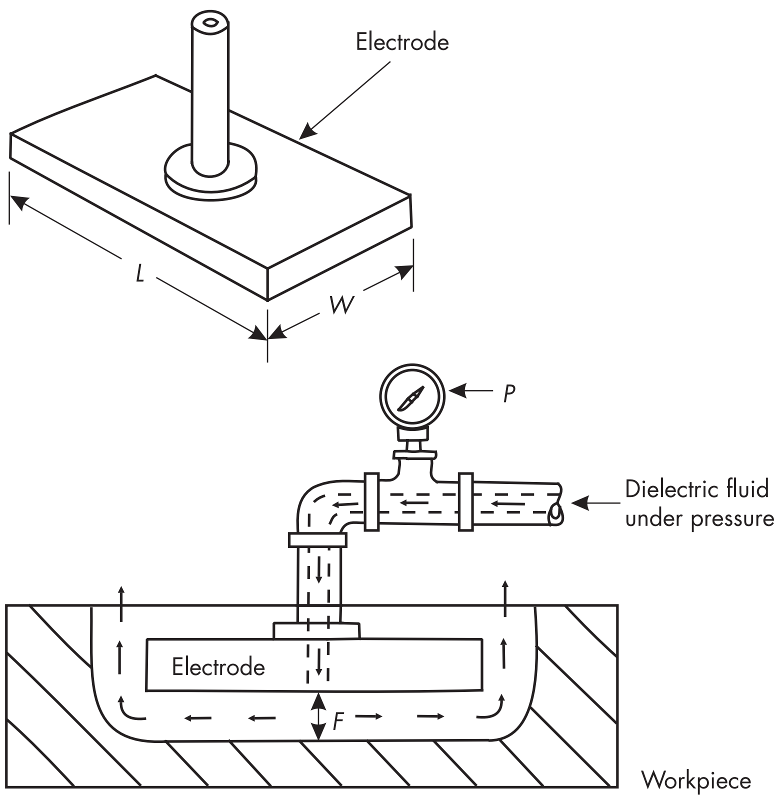
separating force of approximately 200 lb (90 kg) is exerted between the servo head and machine table. With larger electrodes, a very large separating force is possible. Figure 2-7 illustrates this separating force. The machine-column structure, therefore, must be strong enough to prevent flexing during machining. Any flexing will cause a change in the sparking gap and erratic servo operation. Flexing can also cause deformation of the workpiece's machined surfaces.

Servo Head

The servo head is the part of the machine that automatically positions the electrode to the work surface so that sparking will occur. The most common types of servo drives are electric motor and hydraulic. Either type responds to drive signals from the EDM-power supply, by sensing electrical conditions between the electrode and workpiece during sparking. Manual positioning of the servo slide is done at the pushbutton-control station for setup operations.

There must be no front-to-back or side-to-side looseness between the movable slide and the stationary portion of the servo head. Any such looseness will result in erratic servo operation and in possible deformation of EDM-machined surfaces. In addition, to maintain efficient sparking conditions, the movable slide must have very little friction, respond instantaneously, and in very small increments. The way system must be able to support the electrode weight and push against the hydraulic force that is produced by dielectric fluid flowing through the sparking gap.

The EDM-machine-servo head operates under very different conditions, compared to most other machine-way systems. The servo head may dwell for long periods of time in one place, or it may move only a very small distance over a long period of time. During this time, the way system is constantly oscillating back and forth in response to commands from the electronic-servo controller, thus maintaining efficient sparking conditions. Proper lubrication is necessary to prevent the way-surface materials from galling under these conditions. Because of this, some manufacturers prefer anti-friction-ball or roller-way systems.



$F = A \times P$

F = separating force between electrode and workpiece

A = area of electrode ($L \times W$)

P = dielectric-fluid pressure

U.S. Customary Units	**S.I. Metric Units**
$A = 5.0 \text{ in.} \times 2.0 \text{ in.}$	$A = 12.7 \text{ cm} \times 5.08 \text{ cm}$
$= 10.0 \text{ in.}^2$	$= 65 \text{ cm}^2$
$P = 20.0$ psi	$P = 138$ kPa
$F = 10.0 \text{ in.}^2 \times 20.0$ psi	$F = 65 \text{ cm}^2 \times 138$ kPa
= 200 lb	= 90 kg

Figure 2-7. Separating force due to fluid pressure.

Depth-stop-limit Switch

The basic EDM machine includes a switch with an actuating plunger for controlling the depth of the EDM operation. Actuation of this switch stops the EDM-sparking cycle, and in many instances, causes the servo-movable slide to retract to its uppermost position. A micrometer, mounted on the servo-head-movable slide, actuates the limit-switch plunger. In some instances, the micrometer is held in place by a magnetic base. The magnetic-base attachment allows the micrometer to be positioned anywhere along the travel line of the movable slide. For depth-stop setting, the electrode is advanced toward the workpiece's top surface, until very low-energy-level sparking is observed. The servo system then automatically holds the electrode in position above the workpiece surface through the distance of the sparking gap. Sparking surfaces must be previously wetted with dielectric fluid for controlled sparking to take place. During the time sparking is observed, the micrometer is advanced until the switch plunger is actuated. The point when limit-switch actuation occurs is zero, in reference to the workpiece surface. The micrometer is then backed off by the amount required for the depth of cut.

For three-dimensional-cavity machining using multiple electrodes, it may be necessary to place a gage strip of known thickness on the workpiece surface. This will establish the zero reference for use on succeeding electrodes. Since workpiece material will be removed from the sparking area, the depth of cut can be established from the gage surface. Figure 2-8 illustrates the use of a gage block for setting the workpiece's zero-reference surface.

When using a gage for setting the zero reference, good electrical contact must be maintained between the gage and workpiece. Poor electrical contact may cause the electrode to physically contact the gage with possible damage to both. To achieve controlled sparking, the electrode and workpiece should be wet with dielectric fluid prior to setting the gage at a zero reference. When using a gage for setup operations, a very low-spark-energy level must be used for establishing a zero reference. It is always necessary to consider the gage thickness in the depth-of-cut calculation.

Depth control is more precise when electrodes are preset with their ends in a common plane. Redressed or new electrodes can be set up off of the machine and prior to use in the machining operation. Using the

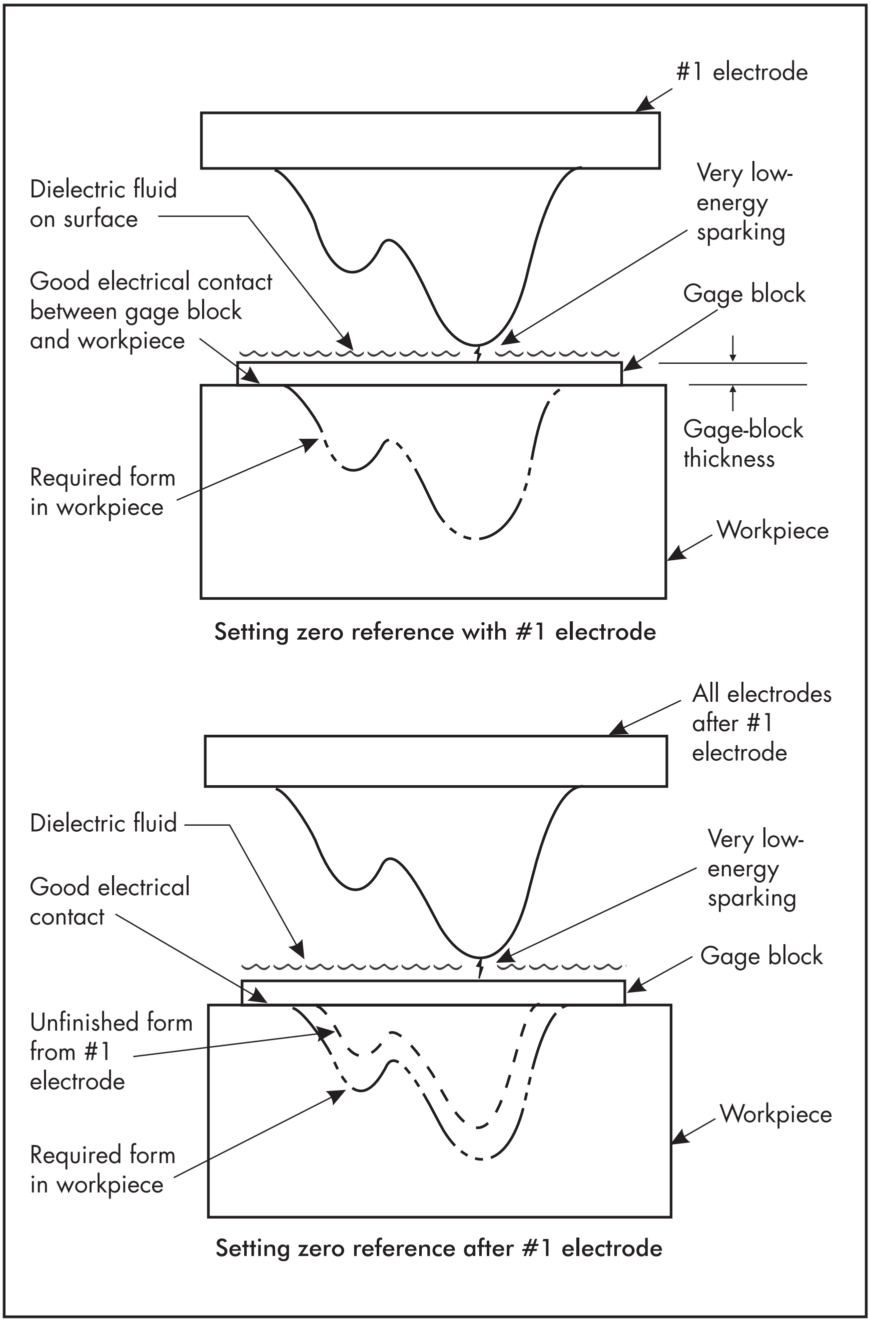


Figure 2-8. Using a gage block to set the zero-reference surface.

preset system, electrodes are interchangeable and can be installed in the machine without any change in the original zero-reference setting.

Servo-feed-rate Indicator

The progression rate of the electrode into the workpiece in many EDM applications can be slow. This is especially true when a large volume of workpiece material must be removed from a three-dimensional cavity. Under these circumstances, setting both the servo-feed control for the greatest stability, and observing the feed rate, can be best accomplished by using a feed-rate indicator. This indicator is often a dial with enough travel to allow observation over a distance of 1 in. (25 mm) or more. A magnetic-base device that slides on a track can actuate the indicator and prevent damage to the indicator. This is true if the magnet is not repositioned prior to the indicator reaching the end of its travel.

EDM machines with CNC control may use an electronic readout for displaying the servo-feed traverse rate. This readout may be included as part of the depth-stop system.

Any servo-feed rate-indicator system should be evaluated for its use and value to the EDM machinist. There is no preferred system. Since machinists are interested primarily in the servo stability and progression rate of the machining operation, some prefer a dial-type readout that can be observed with no need to refer to the numbers. CNC readouts may display the same information, but if it is in digital form, it may be more difficult to interpret quickly.

Servo-head Platen

The platen is the part of the EDM machine where the electrode is normally attached. Platens vary in size and shape to suit the required electrodes and tooling. Since electricity is used for EDM, the electrode and workpiece must be electrically insulated from each other. Many EDM designers choose to insulate the end of the movable servo slide. This allows the remainder of the machine to be electrically grounded for safety. Many platens are made of steel and bonded to the movable slide by an insulating epoxy. The epoxy is often visible in the area where the movable slide and platen are joined.

Some EDM machinists may develop habits that cause concern. For example, when starting the EDM cycle, sometimes the servo head will

not feed forward. This problem is often due to a small wrench or other piece of electrically conductive material being left on the platen and then making contact with it and the movable servo slide. The servo system senses this condition and then interprets it as the electrode being too close to the workpiece for acceptable sparking. It, therefore, commands the servo drive to retract the electrode from the workpiece. But, the electrode is already in its most-retracted position and it cannot retract any further. Nor can it advance, since the servo sensor is issuing a retract command. If a voltmeter is used as a visual monitor on the EDM-power supply, it will show a zero reading when this condition is present. Once the electrical short is removed, the voltmeter will show normal voltage and the servo will feed properly. This illustrates the need to keep the platen surface free of wrenches and any other materials. Should insulated objects be placed on the platen, they may become wedged between the machine structure and the platen during servo-slide retraction. This could result in damage to the machine and possible injury to operating personnel. The platen must be kept clean from dielectric fluid, chips, and sparking-by-product debris. As chips and by-products build up, they can become partially conductive across the platen insulation. This causes deterioration of the servo efficiency.

EDM-power Supply (Generator)

The EDM-power supply is referred to by different names. Manufacturers in the USA often use the term “power supply.” European and Asian manufacturers most often refer to this unit as a “generator,” or “spark generator.” Whichever name is used, it applies to the unit that provides the sparking energy in EDM. The power supply controls the timing of the sparks to the sparking gap and the servo feed, which is used to properly maintain the sparking gap.

The EDM-power supply is probably the least-understood assembly in the EDM-machine system. It is made up of electrical and electronic components. Most EDM machinists do not consider themselves trained or qualified in these areas. While this condition is not likely to change, EDM-operating personnel should become acquainted with the subassemblies within the electronic cabinet and they should understand their importance in the EDM-machining process.

Figure 2-9 illustrates the subassemblies located within the power-supply cabinet. These subassemblies may not appear as separate units, but as printed-circuit boards located in holding racks.

The subassemblies' and systems' operational characteristics and purposes should be reviewed with the manufacturers' installation personnel, service professionals, and application engineers. Most of these people are qualified to explain, in non-electronic terms, what the EDM machinist wants to know. Untrained personnel should not attempt to remove covers and protective panels. Caution should always be exercised when working with electrical and electronic equipment. Recommendations and warnings from the machine manufacturer should be

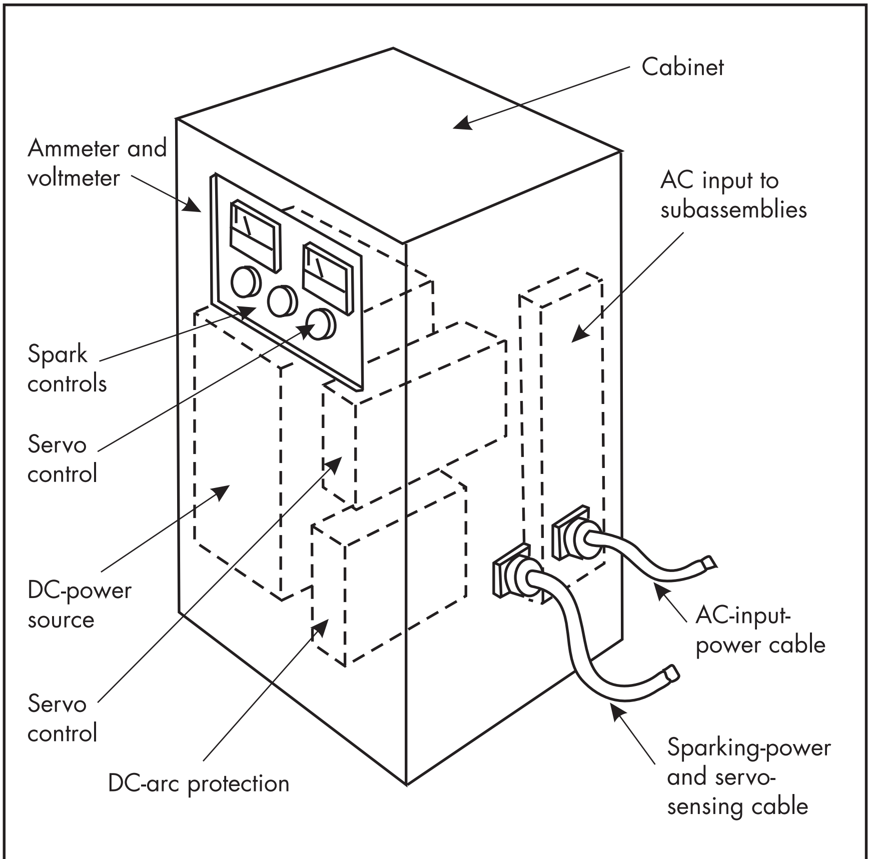


Figure 2-9. EDM-power-supply subassemblies.

followed, because hazardous voltages may be encountered in all EDM-power supplies.

The EDM machinist is primarily concerned with the EDM-power supply control panel. This panel contains controls for setting:

- spark-ON time,
- spark-OFF time,
- peak amperes, and
- servo-feed rate and stability.

These controls, with the exception of the servo, are usually set from engineering data provided by the machine manufacturer. Servo controls are most often set to suit the conditions of each application. The power supply may also include a control for reversing the electrode-to-workpiece polarity. This control is also set from the manufacturer's engineering data. In some instances, the polarity-reversing control may be included in the machine's pushbutton station controls.

A primary consideration in the location of any EDM-power supply in a workplace environment is the atmosphere in which it is expected to operate. The power supply is an electronic assembly that normally uses air from the surrounding atmosphere for cooling. While most EDM-power supplies have air-filtering elements, dust and other materials still find their way into the cabinet. Should materials that are corrosive, oily, or electrically conductive get into the cabinet, the components will fail. The installation area for the EDM machine should be reviewed and approved by a qualified representative from the manufacturer. This will ensure that the surrounding environment does not pose problems with the equipment warranty.

Most power supplies include a voltmeter and an ammeter. These meters are used to monitor the conditions at the sparking gap during the machining operation. The voltmeter indicates voltage between the electrode and workpiece before sparking occurs, as well as during the machining operation. It also indicates servo-system stability during machining. To obtain the most efficient setting for the servo control, the machinist adjusts the controls during machining and observes the voltmeter needle to find the point of least movement. The ammeter indicates the amount of electricity being used for the machining operation.

EDM-power supplies are rated by their ampere output. The higher the amperes, the more workpiece material that will be removed in a

given amount of time. Usually power supplies are rated according to the maximum volume of material per hour that can be removed when using the maximum-ampere output and when machining with a certain set of electrode/workpiece materials with a specified polarity. Maximum metal-removal rates occur with ideal chip-removal conditions, under the most stable servo operation. Maximum metal-removal rates are usually not possible for EDM applications. However, based on the manufacturer's experience, a practical metal-removal rate for any particular application can be established. Using manufacturer recommendations, it is possible to specify the ampere capacity required for the range of work to be accomplished by the EDM machine.

Amperes are provided from a subassembly within the EDM-power supply that may be identified as the "DC-power source." Controls are provided for the machinist to set the peak amperes required for each application. These controls limit the sparking-output amperes to suit the surface finish or the overcut requirements of the machined workpiece. The manufacturer provides engineering data for surface finish, overcut, and metal-removal rate for peak amperes used in conjunction with spark-ON time, spark-OFF time, electrode material, workpiece material, and electrode polarity.

The electronic servo-control subassembly monitors the sparking voltage between the electrode and workpiece. This control compares the sparking voltage to a reference voltage. Based on the comparison between the sparking and reference voltages, the servo controller commands the servo to advance, hold stationary, or retract the electrode from the workpiece. Electronically, the servo control has the capability of responding to sparking-voltage changes within a small fraction of a second. It is important that the machine's servo drive and servo slide respond instantaneously to the servo-control commands. All manufacturers view the match of the power-supply-servo control to the machine servo-drive system to be a very important part of the EDM-machine design.

The spark-sensing and DC-arc-protection systems' subassemblies examine sparks as they occur between the electrode and workpiece. DC arcing is a condition that may cause damage to the electrode and workpiece. As conditions lead toward the establishment of a DC arc, the sparking energy may be reduced and the servo drive then commanded to retract the electrode to an acceptable, electrode-to-

workpiece voltage. The servo will then advance the electrode to re-establish sparking. If conditions are acceptable, normal sparking will resume. Should conditions be unacceptable, spark energy will be reduced and electrode retraction will be re-initiated.

DC-arc-prevention systems work well, except when a DC arc is already established. Once established, the systems do not correct the condition. Should a DC arc occur, the EDM cycle must be stopped and the electrode and workpiece cleaned to remove all traces of DC-arc by-products.

EDM-power supplies accomodate the AC-input voltage that is distributed to the electrical and electronic subassemblies within the power-supply cabinet. This AC-input voltage is normally the same as that for the machine and it is provided through the machine's electrical-control enclosure. If a master-voltage disconnect is provided, the AC-input voltage to all EDM systems can be turned OFF by actuating this switch. This is a safety feature and should be considered prior to installing any machine.

The EDM-power supply is electrically connected to the machine by at least two cables. One cable sends the AC-input voltage to the power supply. The other is for the transmission of spark energy to the electrode and workpiece. A separate sparking-voltage-sensing cable may also be provided. If spark-voltage-sensing wires are included in the spark-energy-transmission cable, or if sensing terminals are set up within the power-supply cabinet, a separate cable may not be provided for spark-voltage sensing. The spark-energy-transmission cable is specially designed to ensure that spark energy is transmitted efficiently, and that it doesn't cause electrical losses between the power supply and machine tool.

Dielectric-fluid Filter-and-storage Assembly

Dielectric fluid must be filtered to maintain its quality. By-products from the sparking process must be removed. The dielectric-fluid filter-and-storage assembly performs this function. Fluid comes from the storage reservoir to fill the machine work tank, to submerge the workpiece, and to flush chips from the sparking area.

Dielectric-fluid filter-and-storage assemblies may be separate from the EDM machine or they may be included as part of the machine structure. In evaluating a dielectric-filtration system, it is important

to review the maintenance requirements for filter replacement and the accessibility of fluid reservoirs for cleaning.

Figure 2-10 illustrates a typical dielectric-fluid filter-and-storage assembly. The reservoir has sufficient capacity to fill the machine's work tank with fluid, plus it has an additional capacity to provide dielectric fluid to the sparking gap for chip removal.

A role of the electrical enclosure is to facilitate electrical connections between the machine and the dielectric-filter-and-storage assembly. The machinist controls the operation of the pumps. The fill pump is normally centrifugal in design to provide a high-volume flow of fluid to the work tank for rapid filling. This design allows the work-tank

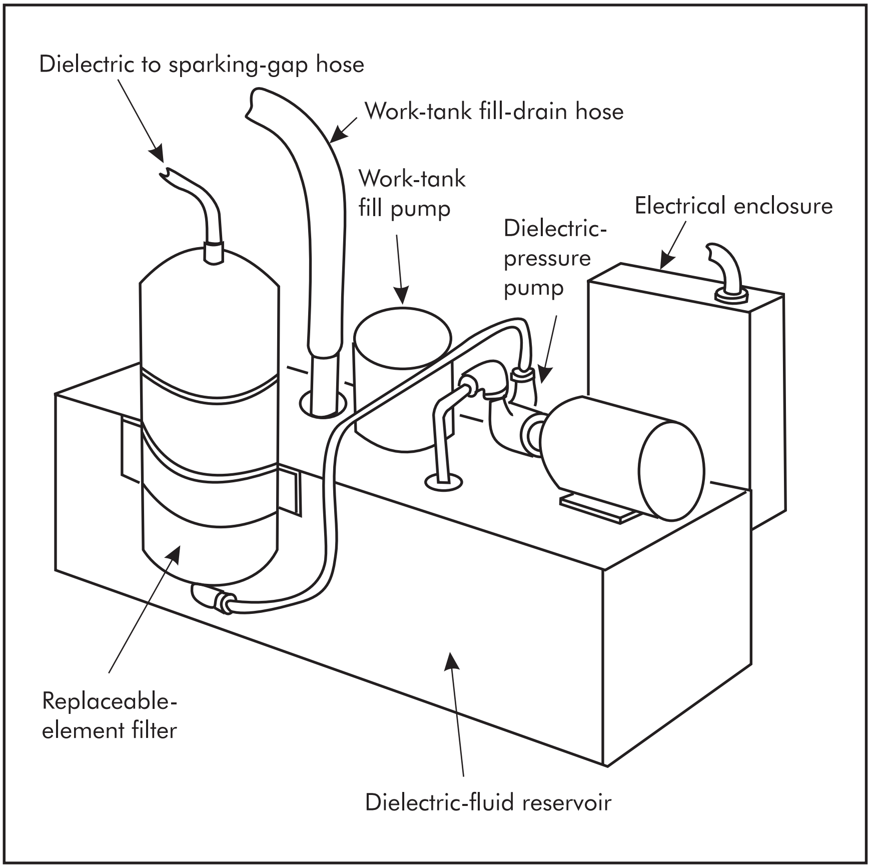


Figure 2-10. Dielectric-fluid filter-and-storage assembly.

fluid to be drained back through the fill pump when emptying the work tank. In operation, the fill pump is started and the work tank is filled to the required level. The fill pump is then turned OFF and a manual valve is actuated to prevent the dielectric fluid from flowing back into the storage reservoir. Draining of the work tank requires that the fill pump remain OFF, and that the manual drain valve be opened.

During the EDM-sparking cycle, the dielectric-pressure pump is activated. This provides filtered fluid to the sparking gap for removal of EDM chips and it ensures that the quality of the dielectric fluid is maintained in the sparking gap.

Most EDM machines include a replaceable-element, cartridge filter to remove EDM-sparking by-products. The filter element's life expectancy is based on hours of use and the amount of material removed from the workpiece. Since amperes are used as a reference for material removal, the working life of the replacement cartridge is usually rated on ampere-hours of machining time.

Fluid under pressure to the machine comes from the pressure pump and filter system. At the machine, a pressure-regulator system usually adjusts the fluid flowing into and through the sparking gap. When the proper amount of fluid is flowing through the sparking gap, EDM chips and sparking by-products are removed at the same rate that they are produced.

Some EDM-machine designers prefer to have filtered dielectric fluid pumped into the work tank and passing through the sparking gap. In this instance, the storage tank has a partition separating the reservoir into two sections. One section is for unfiltered fluid and the other is for filtered. A pump transfers the unfiltered fluid through a filter to the filtered-storage area. All fluid used to fill the work tank, plus that used for EDM-chip removal, is supplied from the filtered-fluid section of the reservoir.

By using filtered fluid in the work tank, the work area is much cleaner. But, this does not ensure that it will remain clean. During high-ampere machining, flushing of the sparking gap causes debris to flow from the sparking gap into the work tank thus discoloring the dielectric fluid. EDM chips and dielectric by-products settle to the bottom of the fluid-storage tanks. When left to collect over long periods of time, the settled material is difficult to break up and remove. As this material collects, it also reduces the storage capacity of the reservoir. Optimum EDM operations require proper maintenance and cleaning of equipment.

Hoses, gaskets, and pumps must not deteriorate while accepting the dielectric fluid. Improper materials used on them will make components fail quickly, due to the abrasive particles in the unfiltered dielectric fluids. It is recommended that only materials approved by the machine manufacturer be used for repair or replacement of hoses, gaskets, and pumps.

Single EDM-machine installations most often use filters that have replaceable-element cartridges. These filters are very efficient. The filter cartridges are available in a range of micron sizes to suit the type of machining performed. Used cartridges should always be disposed of in compliance with environmental codes.

For multiple EDM-machine installations, a central dielectric filtration and storage system is advisable. Filter units are available that automatically cycle for EDM-chip/spark by-product removal. Maintenance is simplified here when overseeing a centralized system, compared to individual machines. Two types of automatic-filter systems commonly used for multiple-machine installations are the diatomaceous-earth filter and the paper-edge filter. Filter media, EDM chips, and fluid by-products must be disposed of in accordance with environmental codes.

When using a dielectric assembly, with a pump for filling the machine's work tank, a fill-drain valve is usually in place to prevent the dielectric fluid from flowing back into the fluid-storage reservoir during the EDM-sparking cycle. Should this valve not be completely closed, fluid from the work tank will leak through it into the fluid reservoir, causing the dielectric-fluid level to lower. If the work tank has a properly positioned, fluid-level-monitoring float switch, the EDM-sparking cycle will terminate when the fluid level drops to the preset level. Should the fluid-monitoring device be positioned improperly, the fluid level may drop to a point where the sparking gap is exposed. This could cause the pressurized fluid, provided for chip-removal flushing, to become atomized in the sparking gap and possibly ignite. EDM machines using air systems to fill the work tank may have the same ignition problems if the air-control drain valve is not completely closed.

WIRE-CUT MACHINES

The basic components that make up a wire-cut machine are quite different than those of the die-sinker machine. Figure 2-11 illustrates

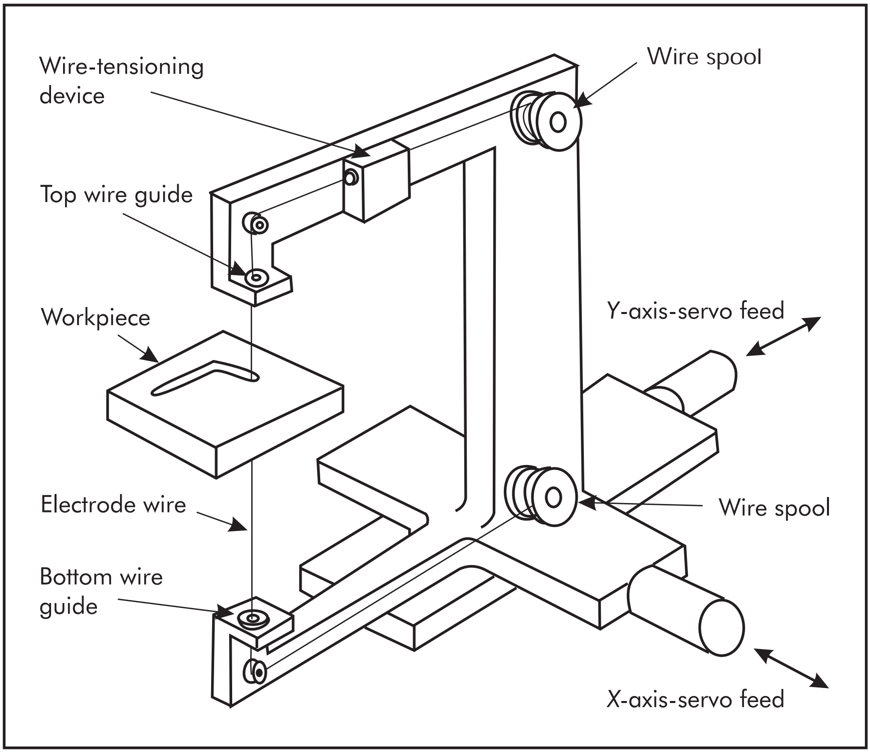


Figure 2-11. Basic wire-cut EDM machine.

one style of wire-cut machine with a fixed-position worktable. It is also possible to have the workpiece supported on a movable *X-Y*-positioning table, with the electrode wire held in a stationary position.

The wire-cut machine's moves are controlled by servomotors, commanded by computer numerical control (CNC). There must always be an opening for the passage of the electrode wire. Precision machining with a wire-cut machine requires very close attention to the travelling-wire-feed system. This includes the top-and-bottom wire guides, the wire-tensioning mechanism, and the condition of the wire on the supply spool. Electrode wire is only used once, since the material removed from the wire surface during the sparking process weakens it. Upon travelling through the sparking area, the used wire is collected for disposal on a spool, or cut into short lengths and dropped into a container.

Wire guides are provided in different styles, designs, and materials. The potential machine user should evaluate the wire-guide design to make sure that it will provide the required machining accuracy necessary over an extended time period.

Two items of importance are not shown in Figure 2-11. These are the electrical-sparking-power contacts to the electrode wire and the elevating mechanism for adjusting vertical distance between the wire guides to accommodate different workpiece heights. For efficient wire-cut-machining operations, the electrical contacts must be clean. A dirty contact will cause machining problems. Contacts should be easily accessible for cleaning and they should be maintained to the machine manufacturer's specification.

The wire-guide elevating mechanism is set to allow proper machining-workpiece heights, within the required range of applications performed. The top wire guide is normally adjustable for workpiece height. The bottom wire guide is fixed in close proximity to the bottom surface of the workpiece. Wire guides should be inspected periodically for wear. They should also be inspected for cleanliness. Worn or dirty electrode guides can cause inaccurate machining and erratic machine operation. The top guide of the elevating mechanism must be set properly so that the mechanical structure will not come into contact with surfaces that project from the workpiece during operation.

WIRE-CUT-MACHINE STRUCTURE

Wire-cut machines were originally introduced as open-style structures. Figure 2-12 illustrates this style. The power-supply controls on these units were very much the same as those used for the die-sinker machines.

Open-style machines were developed using the equipment available at the time. The computer control was usually modified from other types of machine tools. Machining programs were often manually input from punched or magnetic tapes. Wire-cut machines were developed due to a need to make complicated shapes, without using the machined electrode required for die-sinker machines. EDM wire-cut machines represented a major advancement for all through-hole-machining applications. However, since the machining was accomplished in the open, users were concerned about the electrically charged wire and the water used for the dielectric fluid that splashed over the machine and surrounding area.

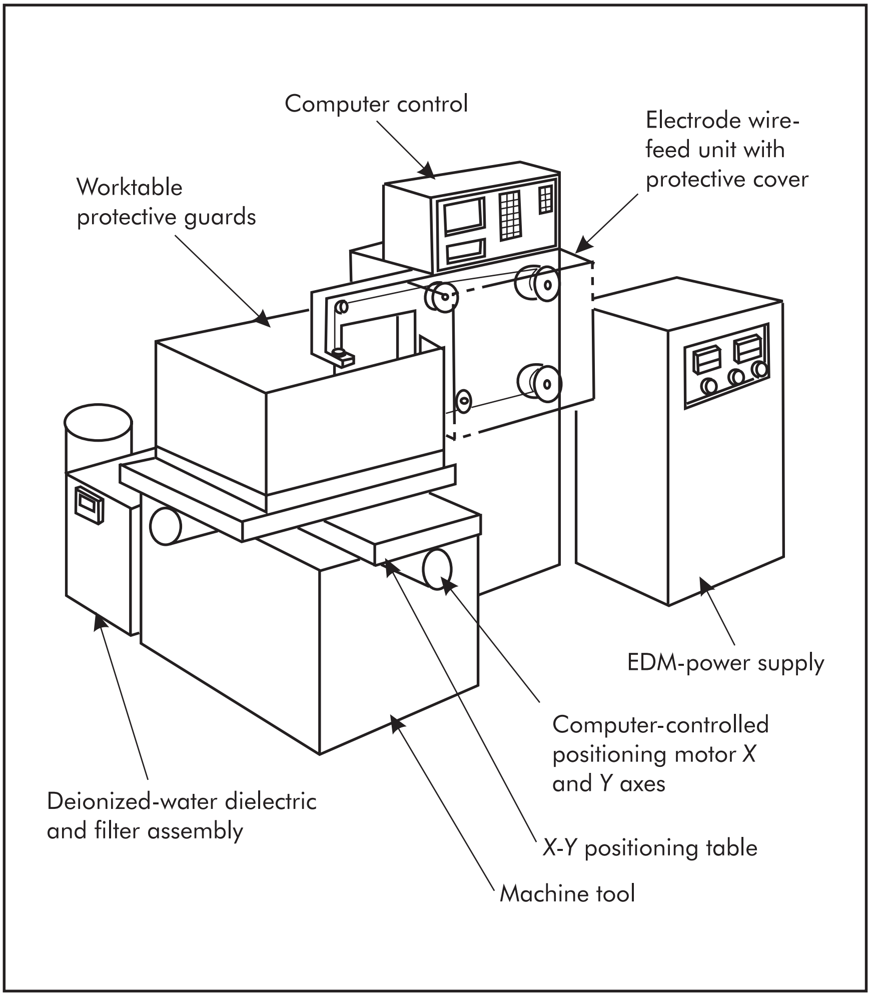


Figure 2-12. Open-style wire-cut machine.

Designers solved these problems by installing a protective cover over the wire-feed unit and installing splashguards around the work area. This open style became a standard for wire-cut machines.

As the wire-cut process developed, it was found that increasing the dielectric-flow rate and pressure also increased the machining speed. With this increase in the dielectric-flow rate and pressure, it was no longer practical to contain the fluid using splashguards. An enclosed-style machine was developed. Figure 2-13 illustrates this update.

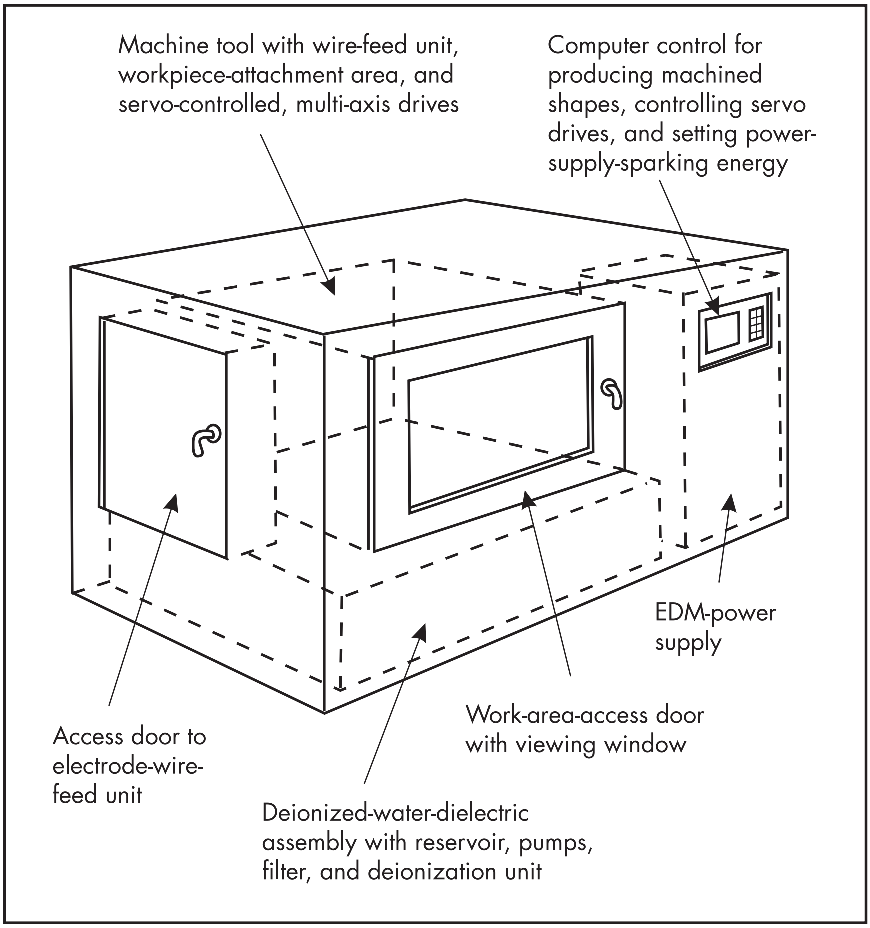


Figure 2-13. Enclosed-style wire-cut machine.

The enclosed wire-cut machine is a self-contained module, designed to protect electronic components from exposure to dielectric fluid. Access to the work area and wire-feed unit is gained through sealed doors. The work-area door normally has a viewing window for observing the workpiece during the sparking cycle. However, with the high-dielectric-flow rates used, it is difficult to see the actual machining area, due to the volume of fluid flowing onto the viewing window. The computer control for this type of machine monitors all of the machining conditions, and in most instances, it visually displays the shape being machined.

Wire-cut machines are available for two-, four-, and five-axis operations. Figure 2-14 illustrates the movement of the axes.

The axes are identified as *X* axis, *Y* axis, *U* axis, *V* axis, and *Z* axis. In operation, the *X* and *U* axes are parallel in the direction of operation, the *Y* and *V* axes are parallel in their operation, while the *Z* axis is perpendicular to the *X-U* and *Y-V* axes. The *U* and *V* axes offset the electrode wire from the vertical position. This offset allows the wire-cut machine to produce vertical machined surfaces on the workpiece when the *U* and *V* axes locate the top wire guide, directly above the bottom wire guide. Angled surfaces are machined on the workpiece by using the *U* and *V* axes to offset the top wire guide from a position directly above the bottom wire guide. The conical shape surrounding the electrode wire illustrates this offsetting.

Z-axis operation may be manually operated or computer controlled. This axis is used to position the top wire guide in close proximity to the workpiece's top surface. Positioning of the top wire guide is necessary to ensure proper flow of dielectric fluid into the sparking area and to maintain EDM-chip removal. Adjustment of the *Z* axis is necessary at any time during the sparking cycle when a change of contour in the workpiece's top surface is encountered. Should the workpiece surface project into the path of the top wire guide, the units could be damaged in a collision.

Major assemblies used in the wire-cut machine are similar in description to those in the die-sinker machine, but are very different in design. Figure 2-15 illustrates these major assemblies, consisting of the machine tool, EDM-power supply, dielectric unit, and computer control.

The computer controls all movements of the wire-cut machine. Manual positioning is possible for setup operations through the computer control. All controlled axes include a feedback system, advising the computer of the location of each slide. Each manufacturer provides a feedback system that best incorporates axis movement and computer control for the precision required in machining operations.

The machine tool also includes the wire-feed unit. This unit controls wire-traverse speed as it passes through the sparking area. Should the wire pass too slowly through the area, the sparking will erode and eventually break the wire. Passing the wire too quickly through the sparking area is wasteful. In addition to controlling the wire-traverse speed, the wire-feed unit must hold the electrode wire under proper tension and keep it taut and straight. Without proper tensioning, the machine-servo

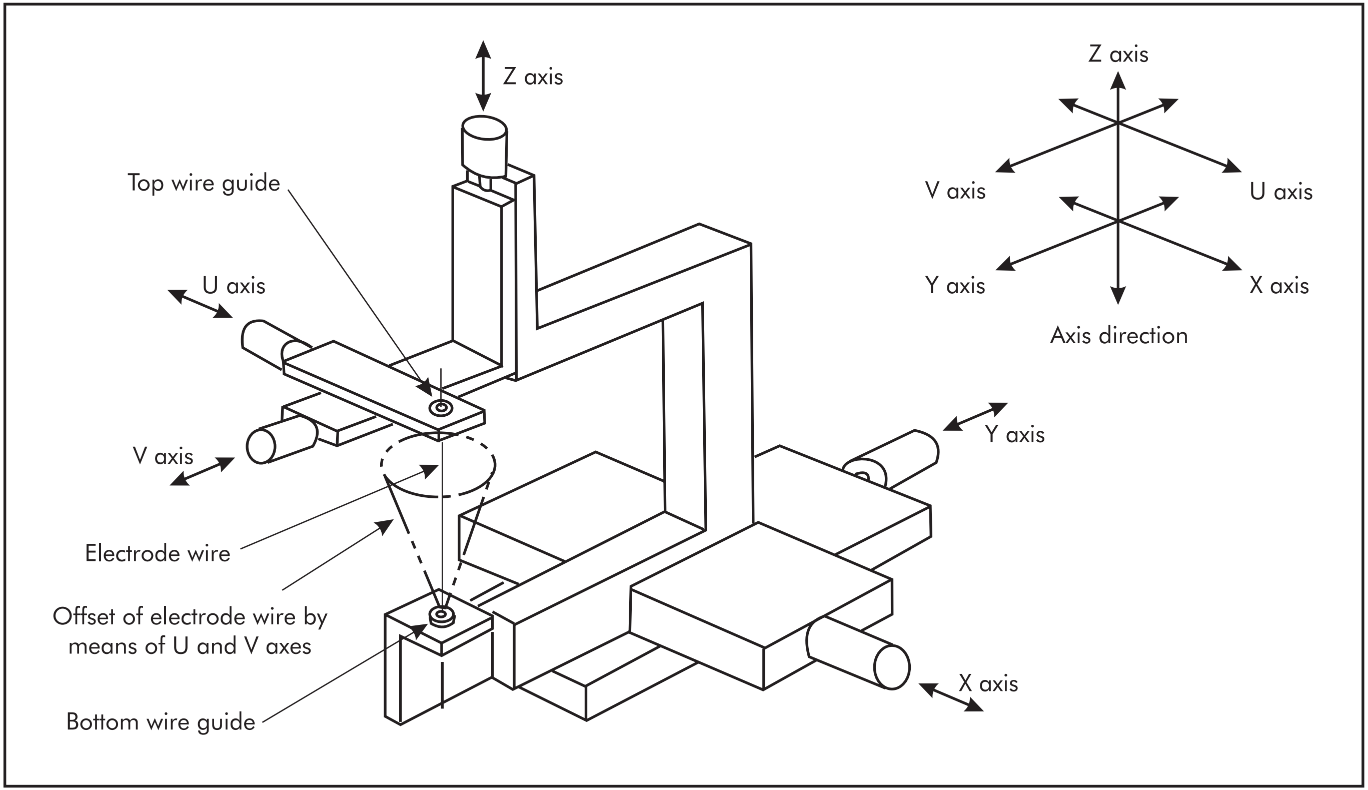


Figure 2-14. Five-axes wire-cut-machine design.

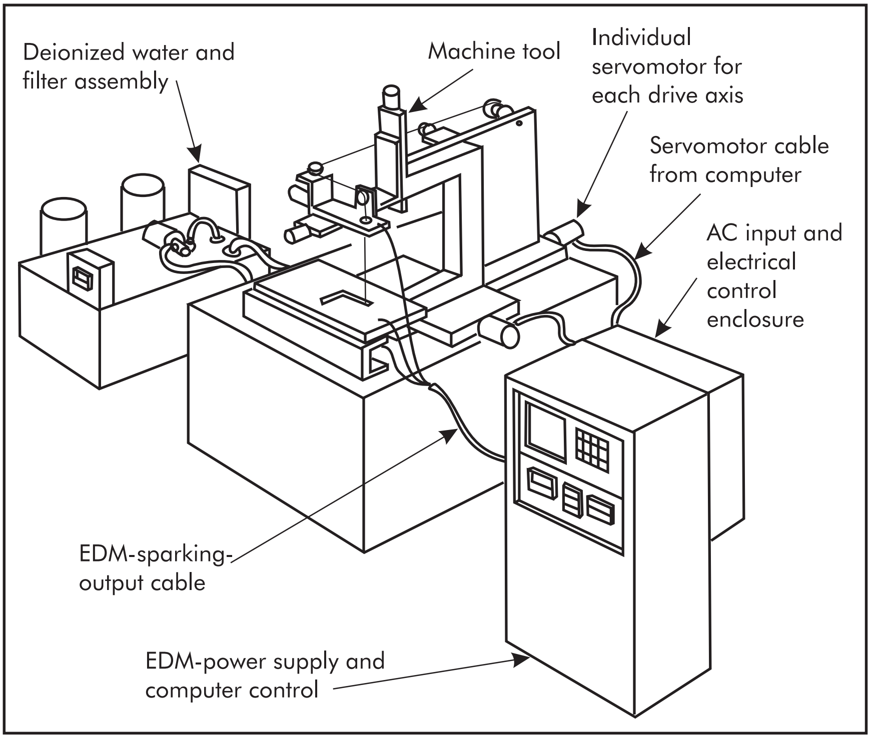


Figure 2-15. Wire-cut machine major assemblies.

system will not function properly and the machined surface will be distorted. Wire-traverse speed is a computer-controlled function that uses settings recommended by the manufacturer. The settings consider items such as the electrode wire's material, diameter, and metallurgy. The workpiece material and thickness also will affect wire-traverse speed.

Wire-cut machines are not always designed so that the workpiece is stationary or so that the electrode wire traverses. Figure 2-16 illustrates a design that moves the workpiece by means of an *X-Y*-positioning table. The electrode wire is stationary, except that the *U* and *V* axes are incorporated in the top wire-guide arm to provide offset during taper-machining operations.

Another design moves both the workpiece and electrode wire. Figure 2-17 illustrates this style. Again, the *U* and *V* axes are incorporated in the upper wire-guide-arm assembly to provide the wire offset required for taper-machining operations.

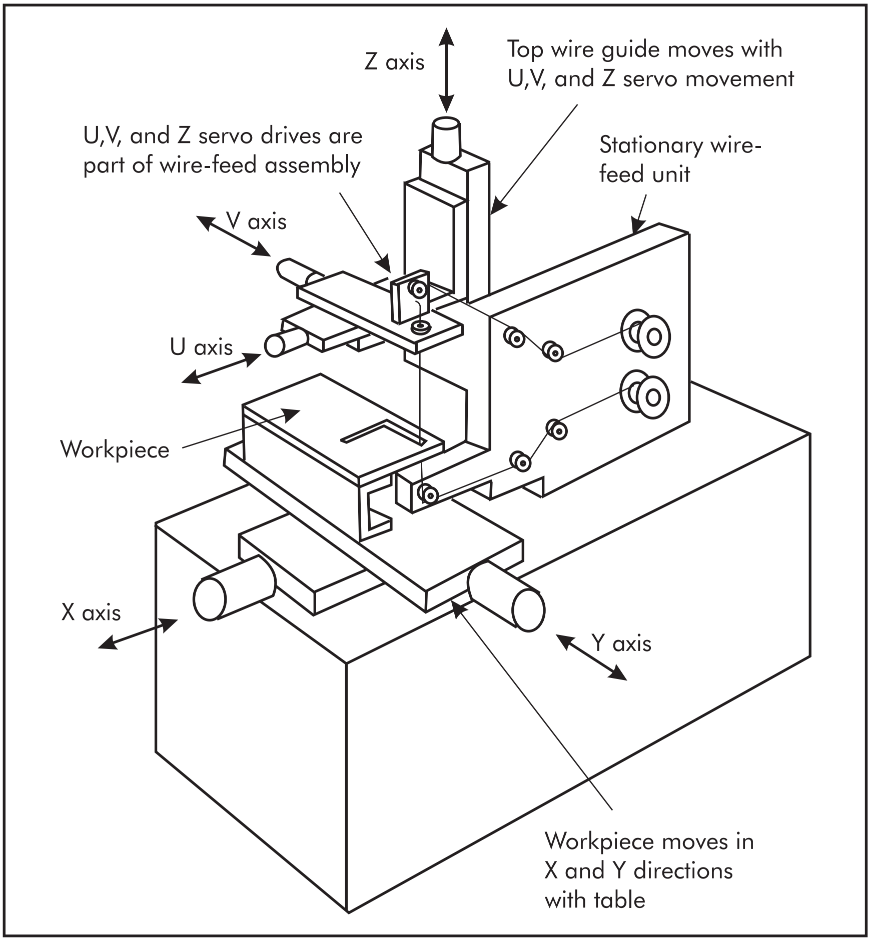


Figure 2-16. Moving-workpiece wire-cut design.

There is no standard design for electrode wire and workpiece movement. Wire-cut-machine designers assemble the machine components to provide the most convenient and efficient operational system for the end-user.

EDM-Power Supply and the Computer

The wire-cut EDM-power supply is very different than that for the die-sinker. Wire-cut machines require the computer to monitor all

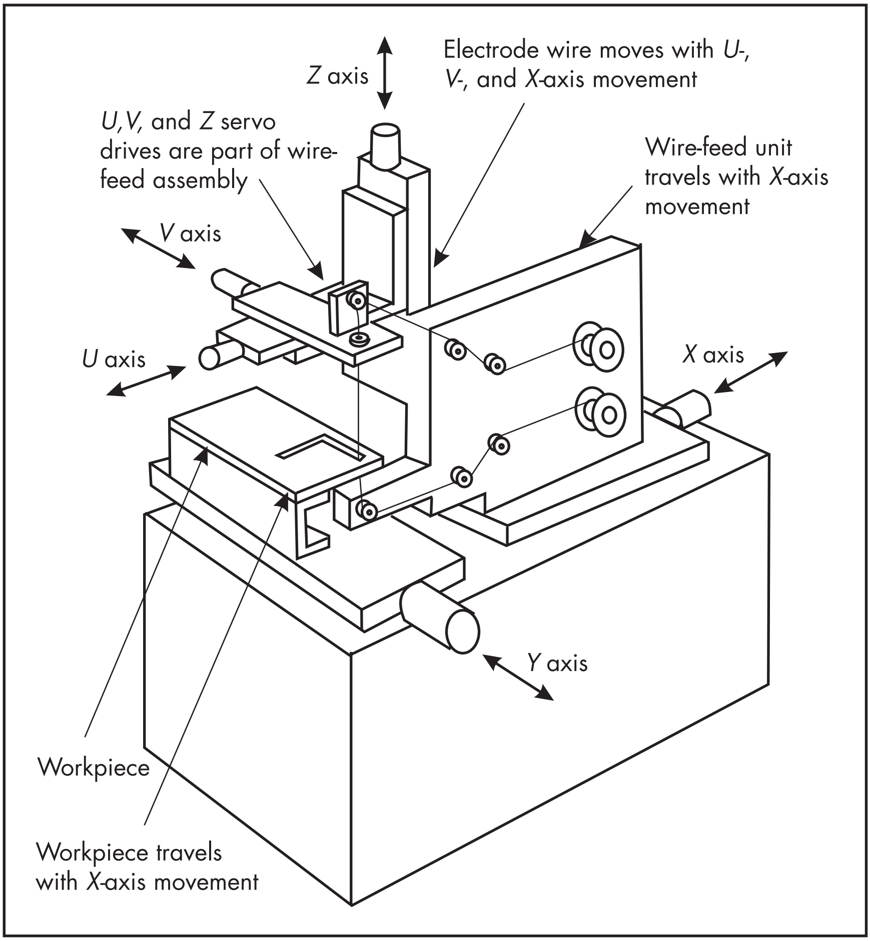


Figure 2-17. Moving-workpiece-and-electrode wire-cut design.

phases of the operation. Since the power supply and computer are basically electronic assemblies, they are often assembled into a common cabinet. Figure 2-18 illustrates a typical power supply and computer assembly.

The foregoing illustration is intended only to identify the subassemblies included in the wire-cut sparking and control systems. Wire-cut machines may also have the computer and electrical control enclosure in the machine as a control center, rather than being part of the power-supply assembly. Wherever the subassemblies are located, they are al-

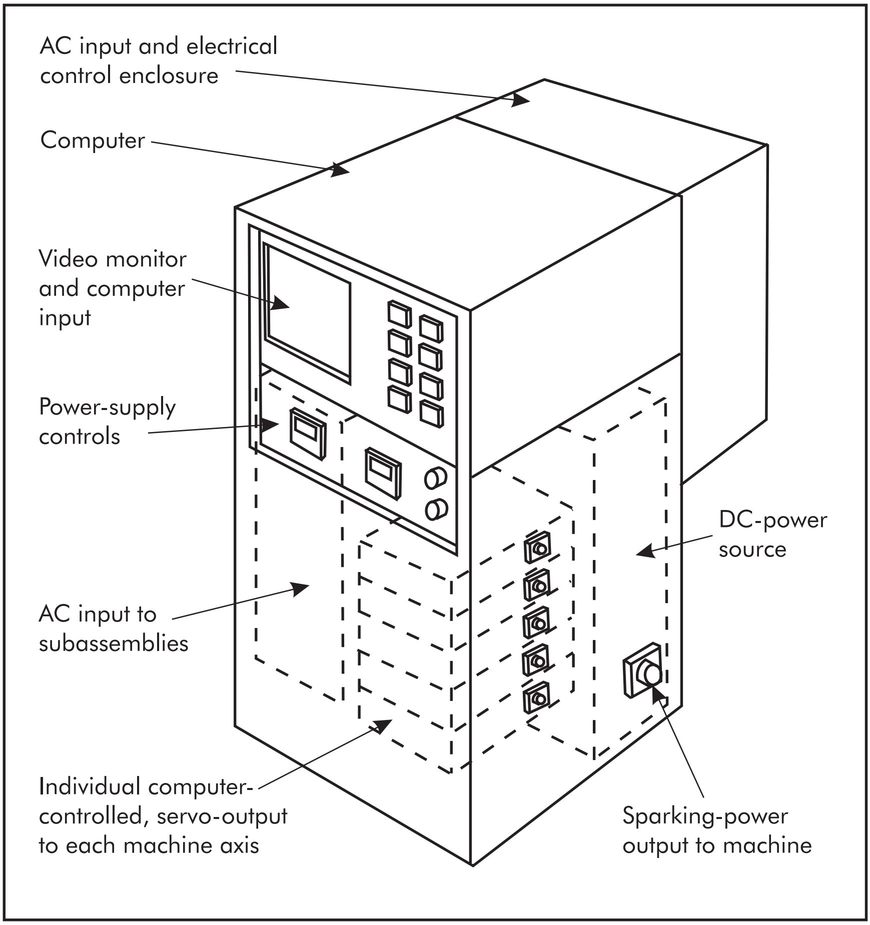


Figure 2-18. Wire-cut power supply and computer assembly.

ways interconnected as an integral part of the sparking and operational control system of wire-cut machines.

Computer control is a necessity for wire-cut machining. The computer is the master control for the power supply, each individual servo drive, the wire-feed system, the deionized-water dielectric system, and the shape machined into the workpiece. Power-supply controls may be separate from the computer-operating panel or they may be included as part of the computer controls. Spark-ON/OFF times and amperes may be manually input at the computer or pre-programmed and entered by means of computer storage devices.

Some wire-cut machine designers include a voltmeter and an ammeter that are separate from the computer-control panel for monitoring workpiece machining conditions. EDM machinists may prefer to monitor the machining conditions using analog meters, rather than a digital display. Movement of the analog needles is usually easier to comprehend than numbers changing on a digital display. Many wire-cut-machine designers include a colored-bar indicator for setting machining conditions. In this instance, machining stability is set using a color on the bar indicator.

Servo operation is controlled by computer software, rather than by a separate servo subassembly within the power supply. Wire-cut machining often requires four axes machining simultaneously. Under computer control, each axis must be monitored individually. The wire-traverse rate must also be monitored and adjusted by the computer to maintain an acceptable sparking-gap voltage between the electrode wire and workpiece. Should the sparking-gap voltage fall lower than is acceptable, the computer will slow the wire-traverse rate to allow an increase in the sparking-gap distance, and a corresponding increase in the sparking-gap voltage. Should the sparking-gap voltage increase above the normal level, the computer will automatically increase the wire traverse speed. This will close the sparking gap and maintain an efficient machining traverse rate.

Wire-cut power supplies are rated in amperes. The electrode wire's diameter and material, along with the thickness of the workpiece, determine the actual machining amperes used. Spark energy is determined by spark-ON time and peak amperes. Settings for spark-ON time, spark-OFF time, and peak amperes are determined for each application using data provided by the machine manufacturer.

Since the computer-control panel is the main operation point of the wire-cut machine, it is important for the machinist to have a master-stop switch as part of the machine controls. Should abnormal conditions be encountered, the machinist must be able to terminate the machining operation before personnel are injured or before the machine is damaged.

The power-supply electrical assembly should include an electrical enclosure for single-point connection of the AC-input power to the machine. This assembly may be separate from the power supply and mounted on the machine or on part of the machine enclosure. As a safety consideration, the enclosure should include a master-disconnect

switch to remove all electrical input when maintenance or service work is performed. The machine must also be electrically grounded, according to the manufacturer's recommendations and all local electrical codes.

The electrical control enclosure should include all of the starters for the dielectric-pump motors and the chiller, along with overload protection for all operating electrical assemblies. Termination points should also be included for any electrical wiring between the subassemblies.

The workplace environment needs to be considered when selecting the location for the wire-cut computer and power supply. Most wire-cut machines use the surrounding atmosphere for cooling air. Dust, grinding grit, and oil mist will degrade electrical, electronic, and computer components. Even with a high level of maintenance effort, this material will eventually become evident in the power supply and computer assemblies. Their presence could cause the components to fail. Manufacturer installation and maintenance recommendations should always be observed to ensure optimum component life and proper machine operation. Temperature regulation also needs to be taken into consideration at the time of installation. Atmospheric-temperature changes will cause changes in the machine structure that will affect the machining accuracy.

Dielectric-fluid and Filtration Unit

Wire-cut machine tools have another important design feature. Because deionized water is very corrosive, the machine-metal components exposed to this water are normally constructed from stainless steel. Figure 2-19 illustrates a typical deionized-water dielectric system.

The dielectric supply is also exposed to the corrosive nature of the deionized water. The reservoir, pumps, plumbing, and filter must all be capable of operating in this environment. The wire-cut dielectric system must filter the sparking by-products from the water after it returns to the storage reservoir. In addition to the filtration, the water must be processed to remove any dissolved materials before it is usable as an EDM dielectric. Deionized water is a dielectric, but it becomes an electrical conductor very rapidly as it accepts dissolved material from the sparking process. To return the water to an acceptable purity level and use it in the sparking process, it is passed through a resin tank to remove dissolved materials and to deionize it.

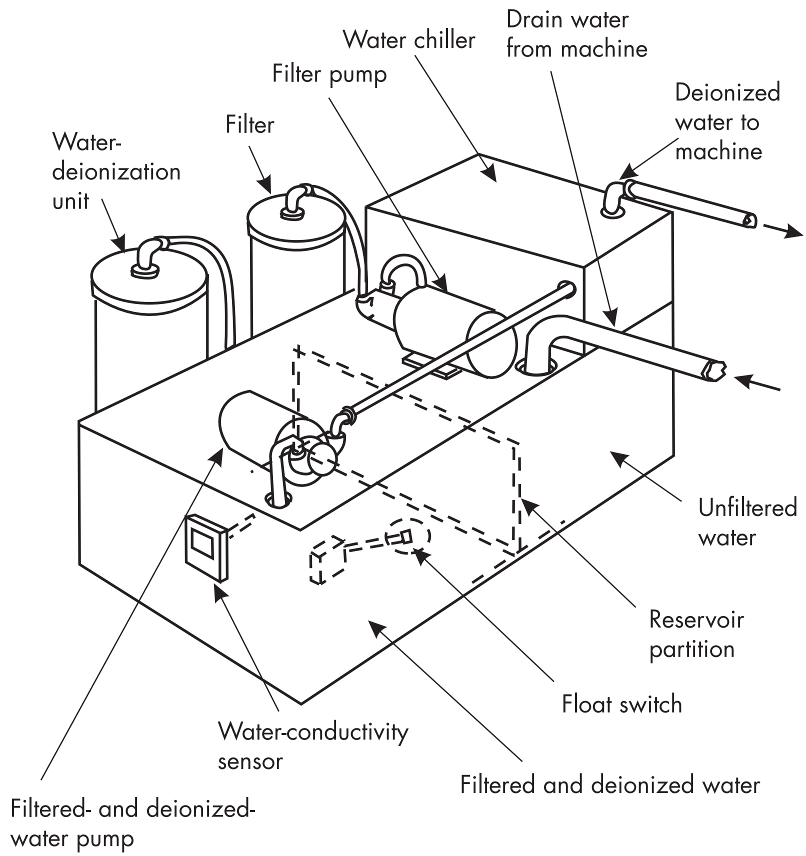


Figure 2-19. Deionized-water dielectric assembly.

Used water from the machine tool is returned to the dielectric-unfiltered reservoir. A partition in the dielectric tank separates the unfiltered water from the filtered and deionized water. Water is pumped from the unfiltered reservoir through the filter to remove the solid EDM debris. The water is then pumped through the resin tank and into the filtered and deionized water reservoir. The filtered and deionized storage tank includes a sensor to monitor the electrical conductivity of the deionized water. Should the electrical conductivity change to an unacceptable level, a warning is displayed on the computer monitor

and it may be impossible to commence an EDM-sparking cycle until an acceptable electrical-conductivity reading is obtained.

A float switch is often part of the deionized water reservoir. This switch sounds a signal at the low-water-level limit and it may display a warning on the computer's video monitor. When a low-water limit is indicated, it may not be possible to commence a machining cycle.

Water evaporates and is lost as mist during the machining cycle. Replacement water may be added from the factory's water supply, if impurities are removed first. The factory's water should be tested for acceptability prior to installing wire-cut machines. It is suggested that the water-test results be discussed with the machine manufacturer.

A water-cooling unit is usually part of a wire-cut-dielectric system. Wire-cut-machining speed is greatly affected by the water-dielectric-fluid temperature. As the water temperature increases, machining speed decreases. Manufacturer recommendations regarding water-dielectric-fluid operating temperatures should be followed carefully.

Sometimes, hydrocarbon oil is used in wire-cut machining. When oil is used, filtration considerations are the same as for die-sinker machines. Exposed sparking is not recommended. Most manufacturers do not recommend using hydrocarbon oil and deionized water in the same machine.

At times, submersing the workpiece is beneficial in wire-cut machining. A workpiece of large size or one having a contoured-top surface should be considered for submersion since the workpiece makes it difficult to properly force the dielectric fluid into the kerf slot. A work tank to contain the fluid is needed for submerging the workpiece. The tank should be sealed at the point of entrance of the bottom wire-guide arm. Since the work tank moves with the worktable, a sealed sliding plate must be part of the work-tank wall to allow movements equal in length to the axis travel in that direction.

3 The EDM Process

IONIZATION

Spark energy is provided to the sparking gap by the DC-power source that is located in the EDM-power supply. The EDM system commands the DC-power source—turning the spark energy ON and OFF and supplying the correct amount of electricity to each spark. Each sparking occurrence between the electrode and workpiece is determined by the strength of the dielectric fluid. Dielectric strength for a typical hydrocarbon-oil fluid is 170 volts per mil. A mil is equal to .001 in. (0.025 mm). Figure 3-1 illustrates the conditions described.

The electrode is advanced toward the workpiece until the closest point between them is equal to .001 in. (0.025 mm). The space between the electrode and the workpiece is filled with dielectric fluid. During the electrode advance time, 170 V is applied between the electrode and the workpiece. This voltage is called *open-circuit voltage,* since there is no electricity flowing between the electrode and the workpiece. With the voltage equal to 170 V and the spacing equal to .001 in. (0.025 mm), the dielectric fluid ionizes and changes from an electrical insulator into an electrical conductor. Electricity flows between the electrode and the workpiece through the ionized dielectric fluid. After ionization of the dielectric fluid, electricity continues to flow through the fluid until it is turned OFF. Once OFF, the dielectric fluid deionizes and the fluid, again, becomes an electrical insulator. This process of dielectric-fluid ionization and deionization occurs for each spark. While EDM machining is in progress, dielectric-fluid ionization and deionization takes place thousands of times each second.

EDM-machine designers often include a voltmeter as part of the power-supply assembly. Voltage may also be viewed as part of a video-monitor display. Often, voltage is used as a reference for machining

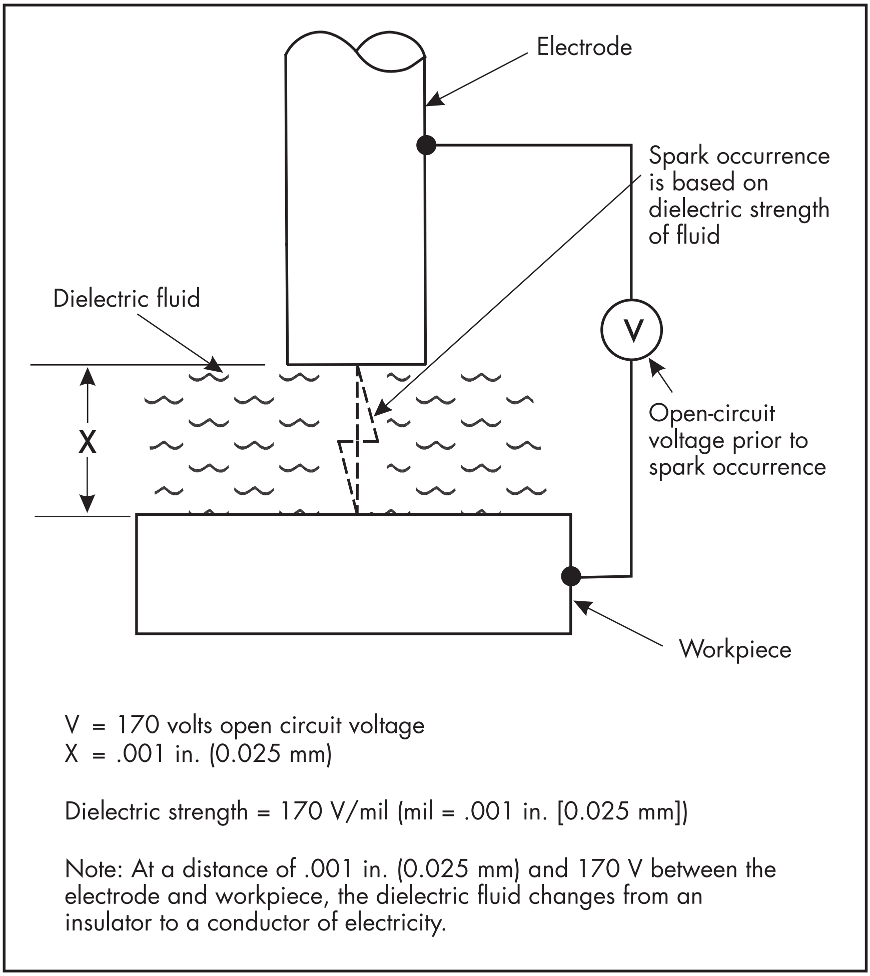


Figure 3-1. Typical hydrocarbon-oil-dielectric strength.

conditions. When the power supply is turned ON, but the electrode is not close enough to the workpiece for sparking to occur, the voltmeter will indicate open-circuit voltage. Voltage indicated during sparking is the *machining voltage*. Open-circuit voltage may be in a normal range of 100–300 V. Machining voltage is normally in a range of 20–50 V. Open-circuit voltage may be considered hazardous and it may require guarding to protect personnel from electrical shock. Manufacturer recommendations should always be observed.

An explanation of ionization requires using the structure of an *atom*—the smallest part of an element—as a reference. Figure 3-2 illustrates only the electrical charges within an atom and not any particular element.

An atom is made up of a nucleus with electrons in orbit around it. The nucleus consists of protons and neutrons. Protons have a positive-electrical charge. Neutrons are electrically neutral, or without an electrical charge. Due to this consideration, neutrons are ignored, since they have no electrical charge and do not affect the electrical relationship between electrons and protons. Electrons have a negative electrical charge. In any atom, the negative electron's electrical charge is always equal to the positive proton's electrical charge. As a result, the electrical charge in a normal atom is zero.

While a normal atom has an equal number of electrons and protons, it is possible to cause electrons to become dislodged and leave their

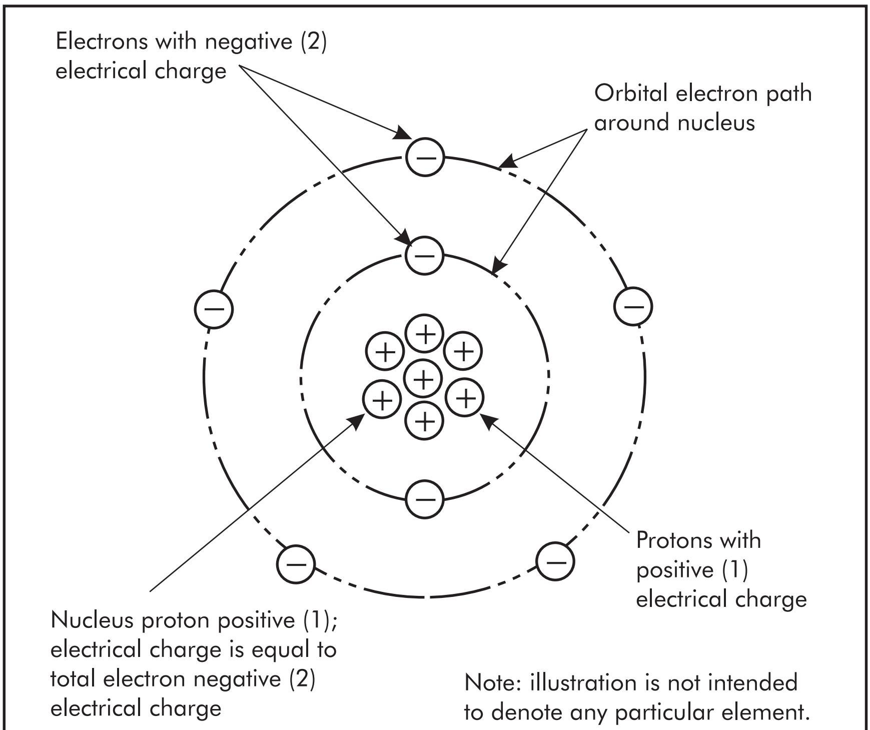


Figure 3-2. Electrical charges within an atom.

orbit around the atom nucleus. A dislodged electron is known as a *free electron*. An atom with a missing electron no longer has equal negative and positive electrical charges. The missing electron causes the atom to become electrically positive and it is then known as a *positive ion*.

Particles having a positive or negative electrical charge interact with one another. For example, like electrical charges repel each other and unlike electrical charges attract each other. Figure 3-3 illustrates how free electrons and positive ions interact with an electrically charged electrode and workpiece.

EDM allows the electrode and workpiece to be connected electrically by either a positive or negative polarity. When the electrode is negatively charged, positive ions are attracted to it and electrons are attracted to the workpiece. Figure 3-3A illustrates this. When the polarity is reversed, and the electrode is positively charged, electrons are attracted to the electrode and positive ions are attracted to the negatively charged workpiece. Figure 3-3B illustrates a positively charged electrode.

To better understand what happens to the dielectric fluid as a spark occurs, keep the following points in mind:

- dielectric strength is based on a voltage and a dimension;
- dielectric strength for dielectric fluid is expressed as a particular number of volts per mil (dimension);
- the dielectric fluid changes from an electrical insulator into an electrical conductor when the voltage and dimension equal the fluid's dielectric-strength rating; and
- the point at which the dielectric fluid changes from an electrical insulator into an electrical conductor is called the *ionization point*.

Figure 3-4 illustrates the condition of the dielectric fluid between the electrode and the workpiece, without voltage applied. Under this condition, the atoms in the dielectric fluid are neutral and have no electrical charge. With no electrode-to-workpiece voltage applied, the dielectric fluid remains in the normal fluid state.

When a DC-power-source voltage is connected to the electrode and workpiece, the dielectric-fluid atoms are affected by the stress between the negative electrode polarity and the positive workpiece polarity. Figure 3-5 illustrates this condition. There is no physical change in the dielectric fluid until the electrode-to-workpiece voltage and dimension are equal to the dielectric-strength rating of the dielectric fluid.

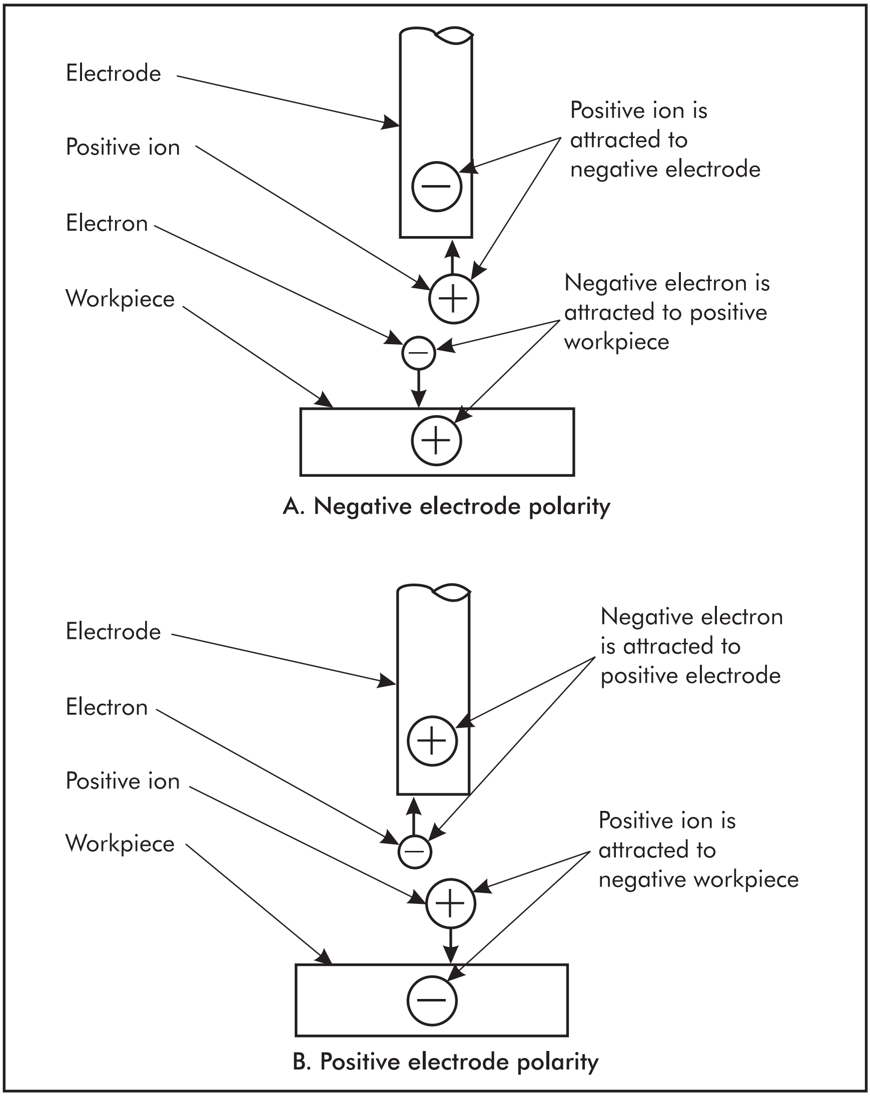


Figure 3-3. Electron and positive-ion attraction to the electrode and workpiece.

At this point, ionization occurs and electricity flows through the ionized column of dielectric fluid between the electrode and workpiece.

Once ionization takes place, the dielectric fluid becomes heated from the flow of electricity and then changes into a gas known as

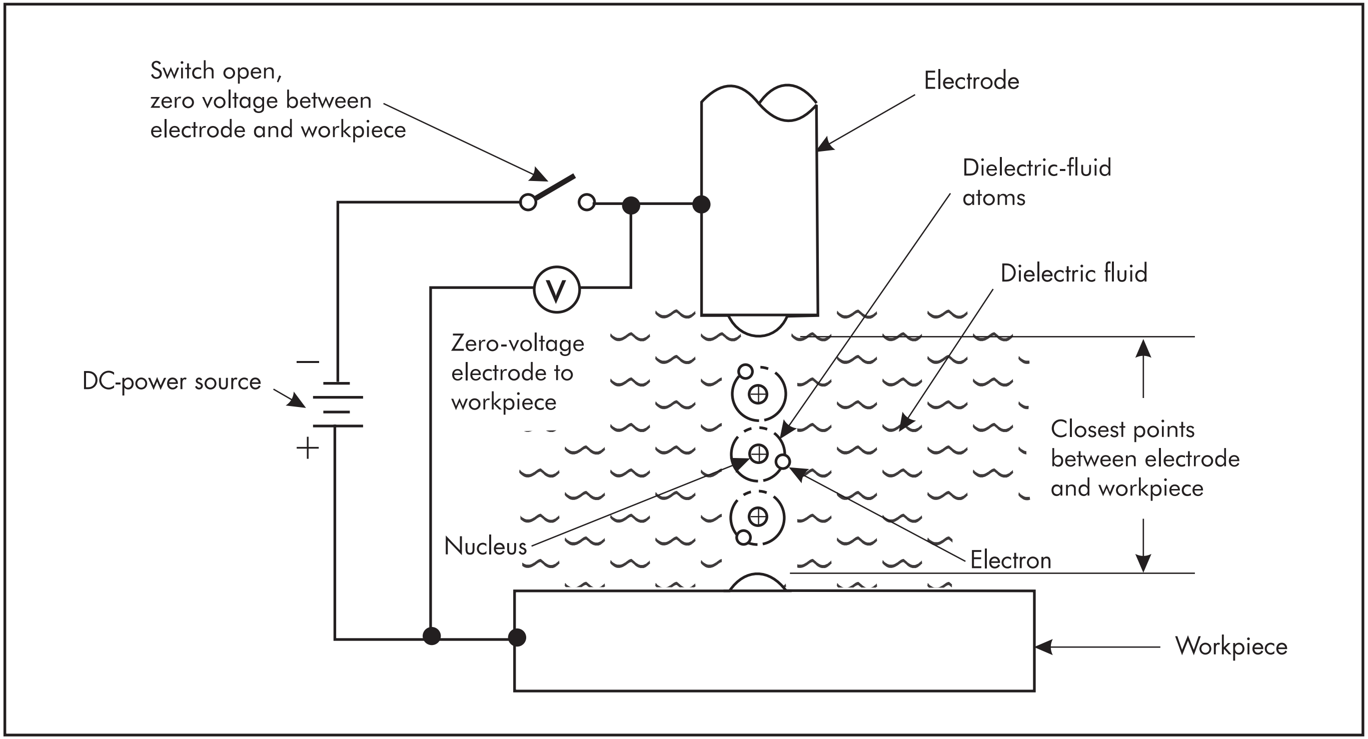


Figure 3-4. Dielectric-fluid atomic charge, without electrode-to-workpiece voltage.

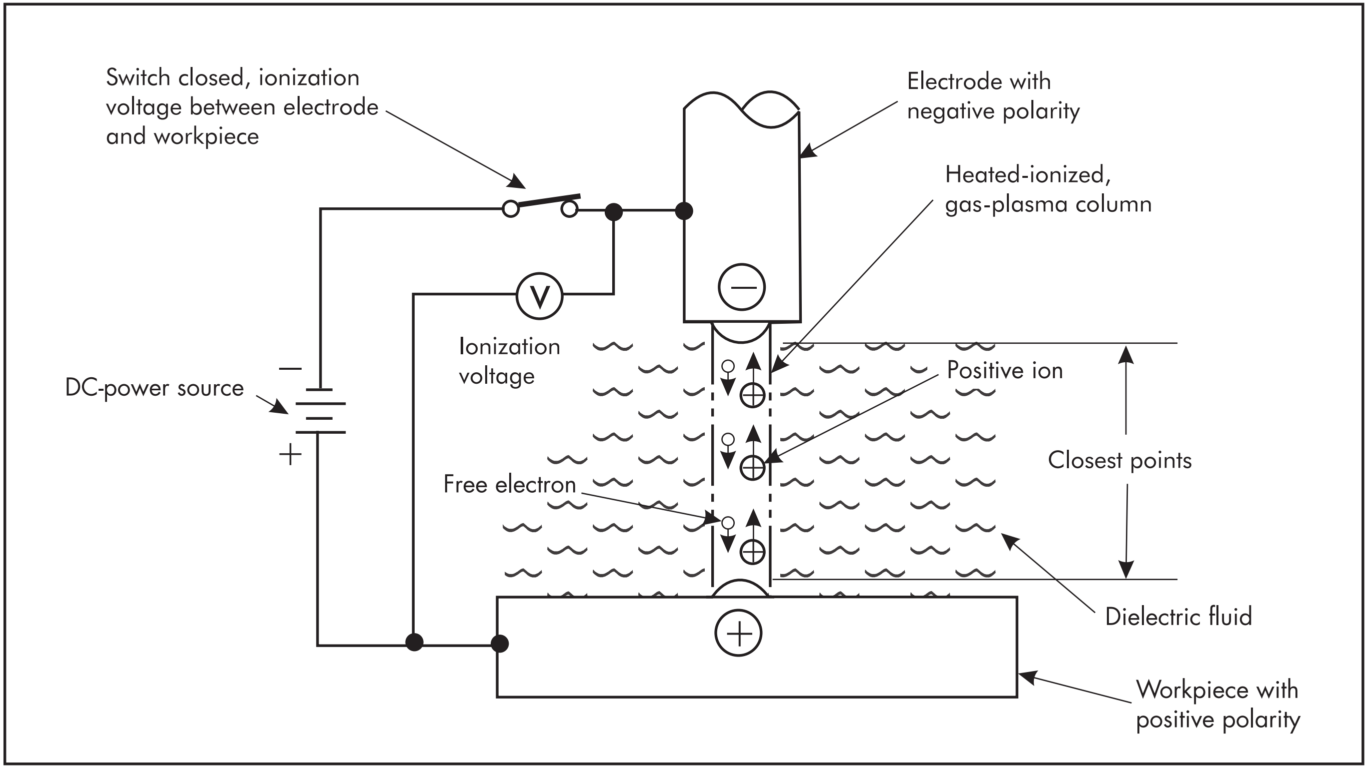


Figure 3-5. Dielectric-fluid atomic charge at time of ionization.

plasma. A characteristic of plasma is that the number of free electrons is approximately equal to the number of positive ions. Under this condition, electrons readily pass through the ionized plasma in the form of a spark.

During the flow of electricity through the plasma, the negative electrons are attracted to the positively charged workpiece and the positive ions are attracted to the negatively charged electrode. The point-of-fluid ionization controls when sparks occur. In normal EDM operations, ionization occurs for each spark and deionization occurs after the electricity for each spark is turned OFF.

DIELECTRIC FLUIDS

Ionization occurs in both hydrocarbon oil and deionized water. Dielectric strength is different for the two materials, but once sparking occurs, the machining voltage is quite constant for either dielectric fluid.

There are differences between hydrocarbon oil and deionized water when they are used as EDM dielectric fluids.

Deionized water allows material to be dissolved into it. The water must be passed through a resin bed to remove the debris absorbed during EDM sparking. It must also be passed through a filtration system to remove the solid by-products created by the sparking process. Passing the water through the resin bed deionizes the water. This is a method for re-conditioning the water into an acceptable dielectric fluid and it should not be confused with the ionization and deionization of fluid in the sparking gap.

Most wire-cut machines include a water quality sensor. This sensor measures the resistance or conductivity of the water. Output from the sensor is displayed on a meter or computer-video display. The reading will normally be displayed in ohms when resistance is used, and in micro-siemens when conductivity is used as the reference. In either instance, the reading refers to quality and dielectric strength of the deionized, filtered water. Manufacturer recommendations should be observed with regard to water quality. Acceptable wire-cut machining can be compromised through the use of water not meeting the manufacturer's minimum requirement.

Hydrocarbon oil does not require deionization prior to reuse. Usually only filtration of the solid sparking debris is required prior to reusing this fluid in the machining process. Tests should be performed and

the machine manufacturer should be contacted for comments and recommendations prior to making any changes in the type of hydrocarbon-oil fluid used. A change in the dielectric strength of the fluid could affect the operation of the EDM machine.

OVERCUT

Overcut is the gap distance between the electrode and the workpiece's machined surface produced by sparking. Figure 3-6 illustrates overcut for the die-sinker and wire-cut machines. Overcut is expressed as a "per-side" dimension. This per-side dimension must be taken into consideration when designing the electrode for die-sinker machines and the programmed path for wire-cut machines.

Sparking overcut accurately follows the electrode shape without regard to size, shape, or number of electrodes in use. Figure 3-7 illustrates some typical shapes, as well as the overcut produced.

The overcut produced from a male-shaped electrode having sharp corners produces a corner radius in the machined workpiece because all of the sparks produced from the electrode corner are the same

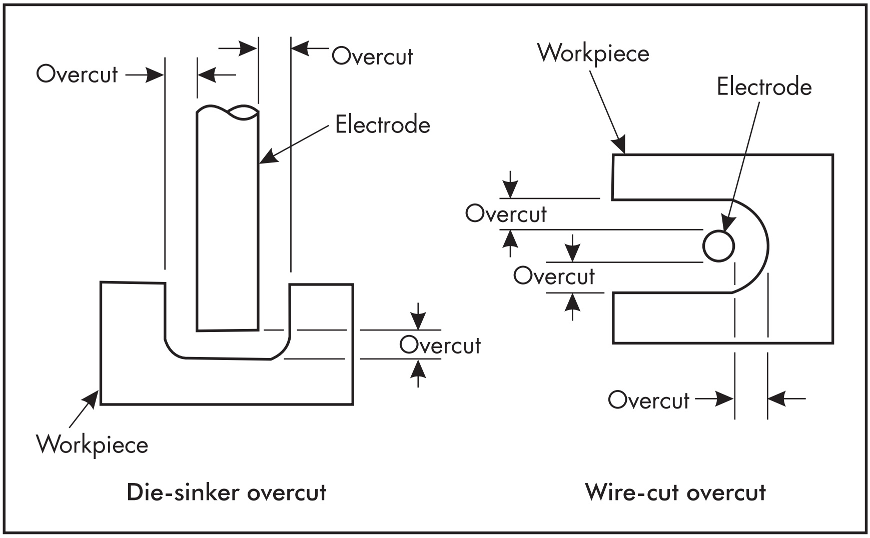


Figure 3-6. EDM-per-side spark overcut.

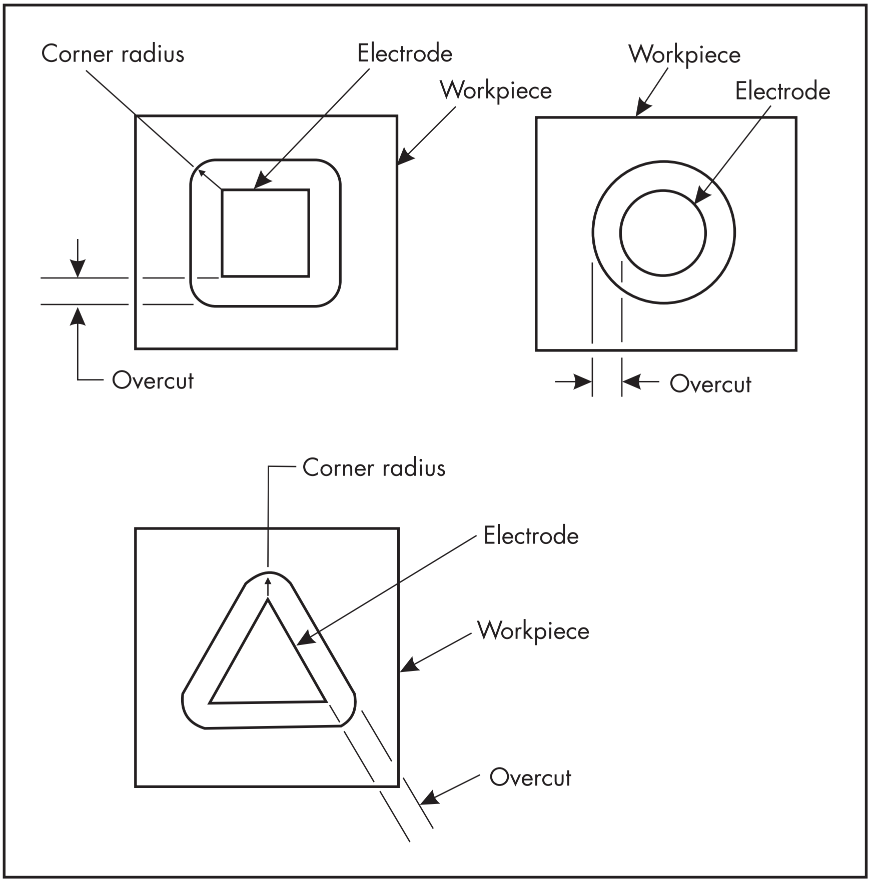


Figure 3-7. Overcut follows electrode shape.

length. Since all of the sparks are equal in length and originate from a common center point, the sparks represent the radius of a circle and produce an arc with a radius equal to the overcut dimension. In most instances, this radius is not large enough to be a problem. The corner radius is considered beneficial in many applications because it eliminates a sharp corner that could produce a high-stress point.

Overcut is determined by the dielectric strength of the dielectric fluid. Dielectric strength is specified as a voltage and a dimension at which the dielectric fluid changes from an electrical insulator to an electrical conductor. A typical hydrocarbon oil may have a dielectric strength of 200 V per mil (.001 in. or 0.025 mm). This rating is based on new dielectric

fluid that has never been used. EDM machines often use an open-circuit voltage of 100 V. The spark-length distance for a machine using an open-circuit voltage of 100 V may be calculated for this particular dielectric fluid using a ratio formula. Figure 3-8 illustrates this formula. Based on a fluid-dielectric strength of 200 V per mil (.001 in. or 0.025 mm), and an EDM-machine open-circuit voltage of 100 V, the spark length (overcut) is equal to .0005 in. (0.0127 mm).

Overcut is variable and not a fixed dimension. Manufacturers provide data for producing overcut dimensions within the range of the machine provided. Figure 3-9 illustrates a simple overcut chart for a 20 A-output die-sinker machine.

Overcut data specifies items such as workpiece and electrode materials, electrode polarity, spark-ON and -OFF times, and peak machining amperes. It is possible that overcut data may be supplied in chart form, rather than graph form. In either instance, the machine settings are those used to obtain a particular spark overcut.

Figure 3-9 shows how overcut is capable of being set in an approximate range of .0006–.0040 in.(0.015–0.100 mm). This would appear to be in conflict with the statement that the strength of the dielectric fluid

$$\frac{\text{Dielectric voltage}}{\text{Dielectric dimension}} = \frac{\text{Open-circuit voltage}}{\text{Spark-length dimension}}$$

U.S. Customary Units

$$\frac{200\text{ V}}{.001\text{ in.}} = \frac{100\text{ V}}{x}$$

$$200x = .1$$

$$x = .0005\text{ in.}$$

S.I. Metric Units

$$\frac{200\text{ V}}{0.025\text{ mm}} = \frac{100\text{ V}}{x}$$

$$200x = 2.54$$

$$x = 0.0127\text{ mm}$$

Dielectric-fluid dielectric strength = 200 V/mil
(mil = .001 in. [0.025 mm])
EDM-machine open-circuit voltage = 100 V
x = point at which dielectric fluid changes from an electrical insulator to an electrical conductor (point of ionization)

Figure 3-8. EDM-spark length based on dielectric strength.

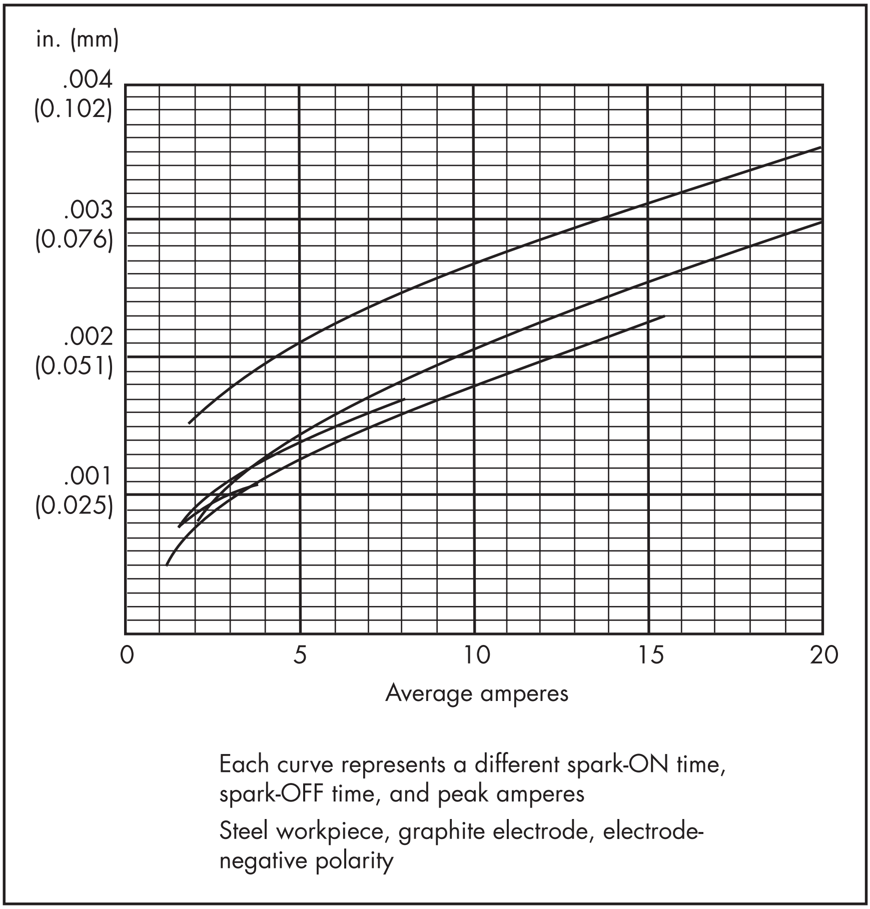


Figure 3-9. Typical die-sinker-overcut chart.

determines the point of ionization and there is only one overcut for the 100-V open-circuit machine. The apparent conflict is because the dielectric strength ratings are based on pure fluid, without any other materials present. During EDM operations, thousands of sparks are produced per second. This results in thousands of electrically conductive chips in the sparking gap. The filtration system does not completely remove all of the solid materials from the fluid. Filters are rated in microns, which is a way of describing the size of the particles that will pass through the filter. Figure 3-10 illustrates the conditions during machining.

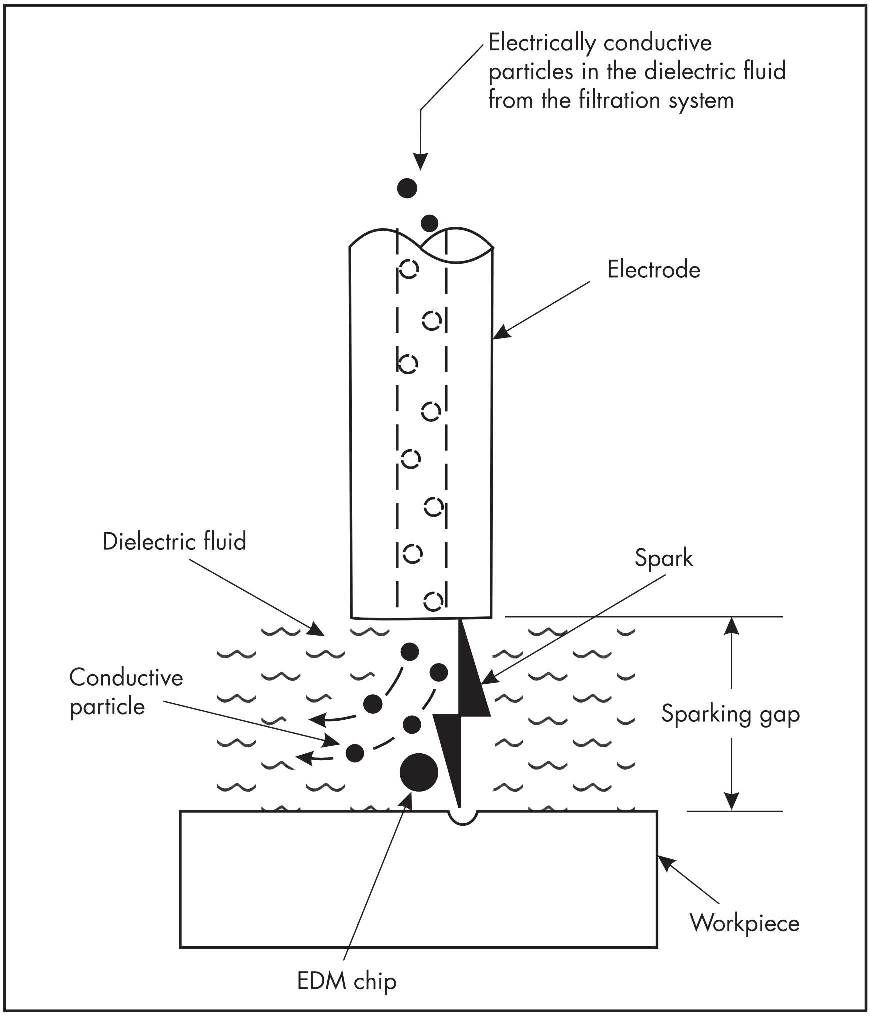


Figure 3-10. Electrically conductive chips and particles in sparking gap.

Since the chips and particles in the sparking gap are electrically conductive and have physical dimensions, their presence must be considered in determining spark overcut. Figure 3-11 illustrates the effect these items have on the dielectric-spark length, which is based on the fluid's dielectric strength. The overcut includes a fixed-length spark that is based on the fluid's dielectric strength, and the size of the chips and particles as they line up to spark a conductive path at the time of

ionization. The size of the EDM chip is the only variable. Chip size depends on spark energy. Low spark energy produces small chips and a smaller overcut. High spark energy increases the chip size and spark overcut.

There are instances where a larger-than-normal overcut is desired to allow the passage of more dielectric fluid through the sparking gap for chip removal. An example would be in the use of a die-sinker EDM

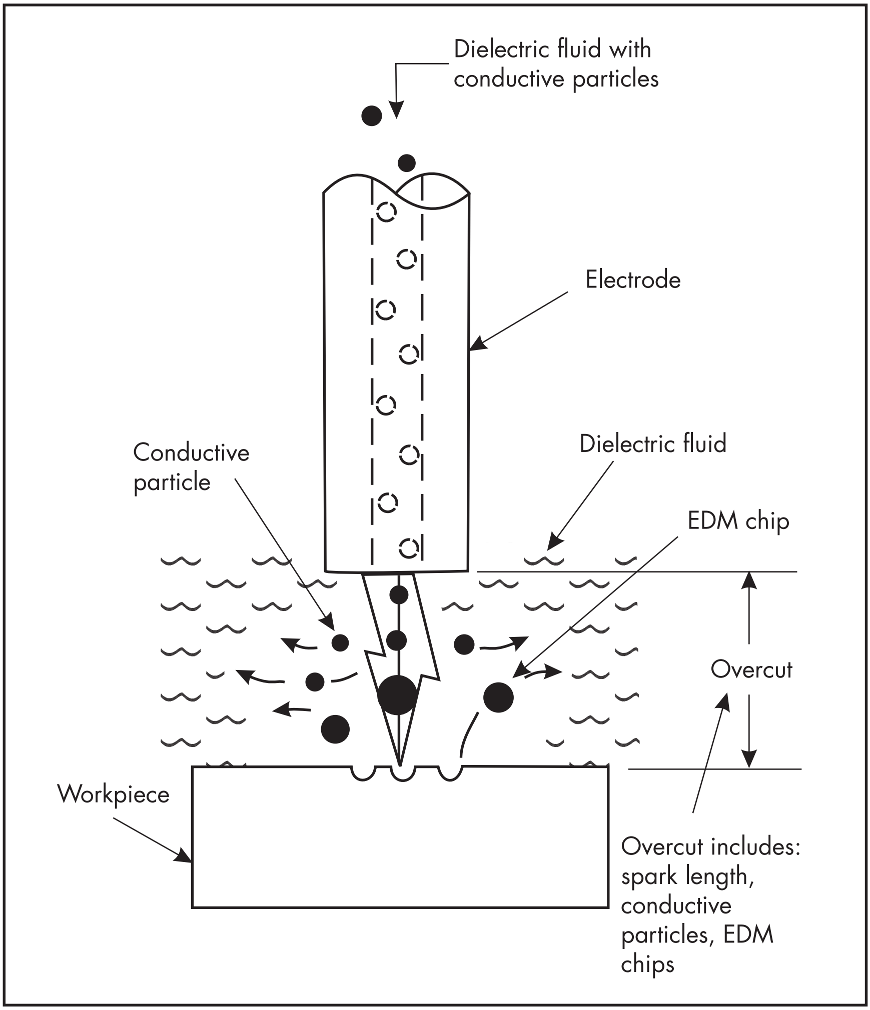


Figure 3-11. Overcut includes spark length, plus chips and particles.

machine for sinking large, three-dimensional cavities. In this application, dielectric-fluid filtration is reduced to allow larger particles to pass through the filter. These particles, along with the size of the EDM chips, effectively increase the spark overcut. When this approach is used, EDM-servo stability can suffer when low spark energy is attempted because large chips flow through the sparking gap during finishing operations.

Another method used to increase spark overcut is to add material, such as graphite powder, to the dielectric fluid. The added material should not be detrimental to the pump and filter elements, and it should be of a size that will maintain an optimum population of particles passing through the sparking gap. The amount of additive in the dielectric fluid must be closely monitored to ensure spark consistency.

Fluid filtration is a major consideration when considering the use of an additive to increase spark overcut. While maintaining the required-additive population, the sparking adds EDM chips and sparking debris to the fluid. The EDM chips and sparking debris need to be removed by the filter. The filter will also remove at least some of the additive material. At some point, more additive material must be added to the dielectric fluid to maintain the proper additive population level.

Filtration of the solid material from EDM sparking must also be considered for overcut during wire-cut machining. In addition, water quality must be maintained within the manufacturer-prescribed limits. The dielectric strength and overcut of deionized water will be detrimentally affected if the resin bed is not properly maintained to remove the dissolved material.

MATERIAL REMOVAL

The EDM process removes material by thermal energy, an indicator that heat is involved. The temperature at the spark is actually high enough to vaporize the material. Thermal energy is provided by electricity flowing between the electrode and workpiece in the form of a spark. Amperes are used to denote the amount of electricity used in the machining process. Increasing the amperes also increases the amount of material removed.

The definition of an *ampere* is based on the rate of flow of electrons. One ampere is equal to 6.25-billion billion (6,250,000,000,000,000,000

or 6.25×10^{18}) electrons passing a given point in one second. This is the number of electrons passing between the electrode and the workpiece in one second for each ampere of machining electricity.

An interesting fact to consider regarding the flow of electricity in the EDM spark is that electricity travels at nearly the speed of light, which travels at a speed of 186,000 miles (299,274 km) per second. For a point of reference, light and electricity travel at a speed approximately equal to seven times around the world at the equator in one second. Since the sparking gap between the electrode and workpiece is normally in a range of .001–.004 in. (0.025–0.100 mm), the flow of electricity across the sparking gap may be considered instantaneous.

Ionization of the dielectric fluid allows the spark electricity to flow between the electrode and the workpiece. Electricity is the flow of electric charges. Figure 3-12 illustrates the flow of electrons from the electrode with a negatively charged polarity to the workpiece that has a positively charged polarity.

During each spark, millions of electrons flow between the electrode and workpiece at the approximate speed of light. The electrons travel easily through the ionized column of dielectric fluid, but the surface of the workpiece is an obstacle. As electrons bombard the workpiece, releasing their energy in the form of heat, this vaporizes the workpiece surface into a cloud. Since the workpiece has positive polarity, the vapor cloud is also positively charged. This positively charged vapor cloud is attracted to the negatively charged electrode. During the time that the vapor cloud is in transit toward the electrode, the spark electricity is turned OFF. This eliminates the vapor cloud's electrical attraction to the electrode. The dielectric fluid deionizes and the vapor cloud is cooled to form an EDM chip. Figures 3-13 through 3-16 illustrate this process.

The bombardment taking place within the ionized column of dielectric fluid is, in reality, more complex than described. During the spark, electrons are freed and attracted to the positive polarity. The atoms from which the electrons were removed become positive ions and are attracted to the negative polarity. Figure 3-17 illustrates the movement of electrons and positive ions within the spark-ionized column when the electrode has negative polarity.

When using negative electrode polarity, there are two actions taking place. Negative electrons bombard the positive workpiece surface and positive ions bombard the negative electrode surface. This

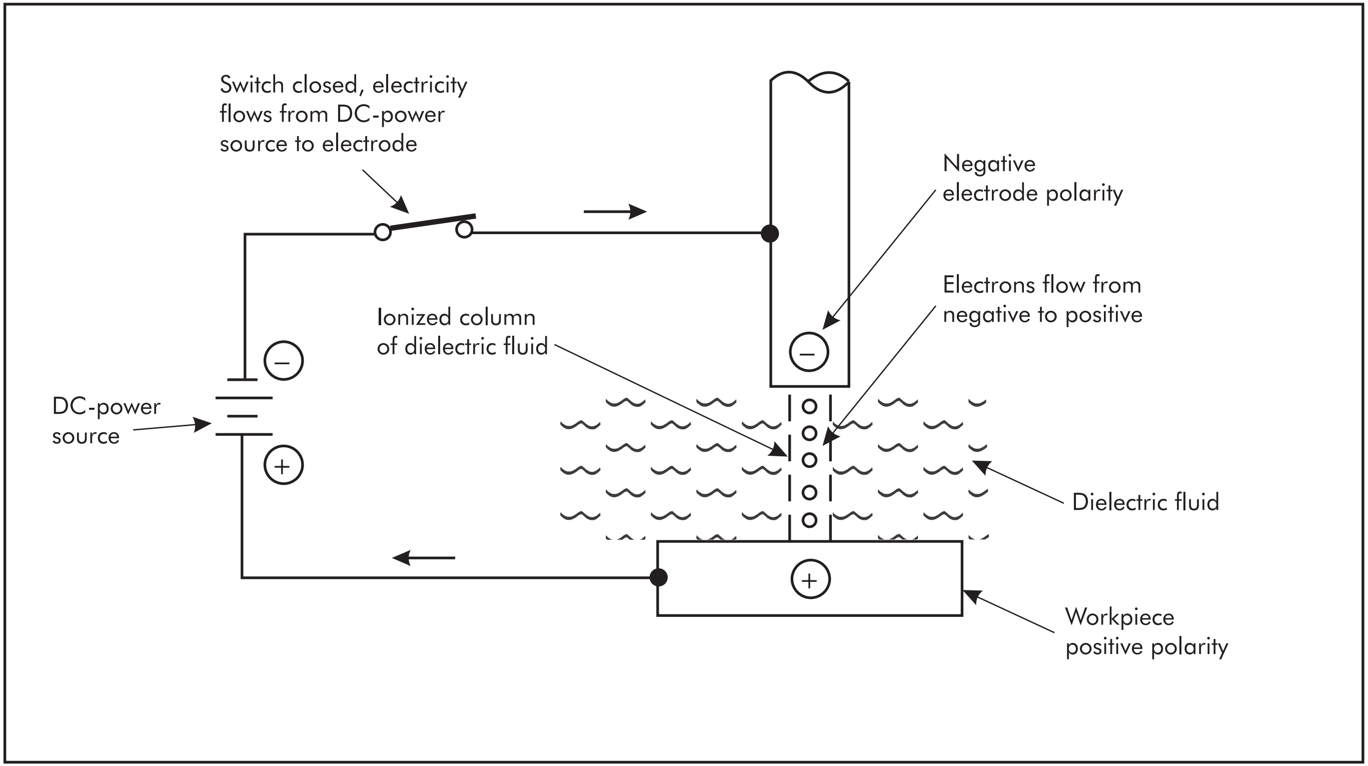


Figure 3-12. Spark-electron flow with negative electrode polarity.

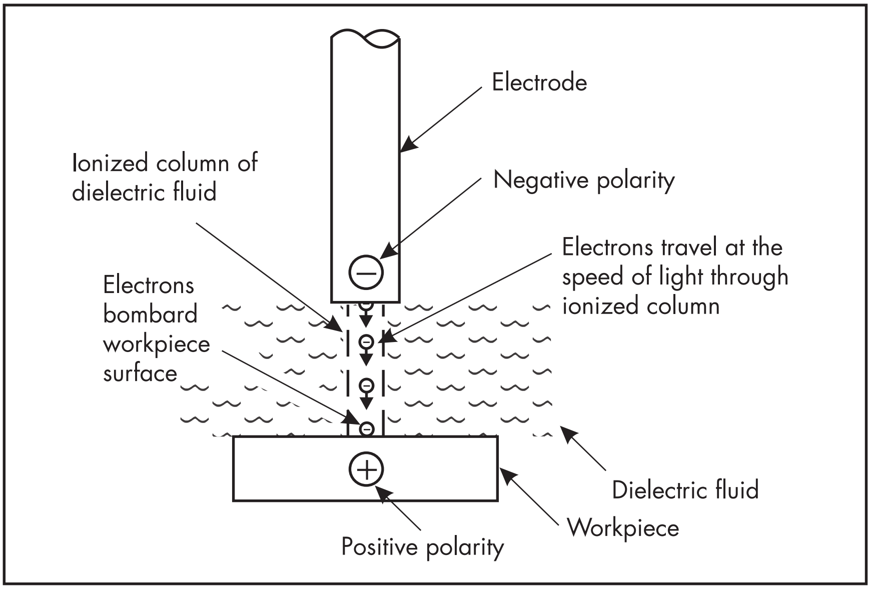


Figure 3-13. Electrons bombard workpiece surface.

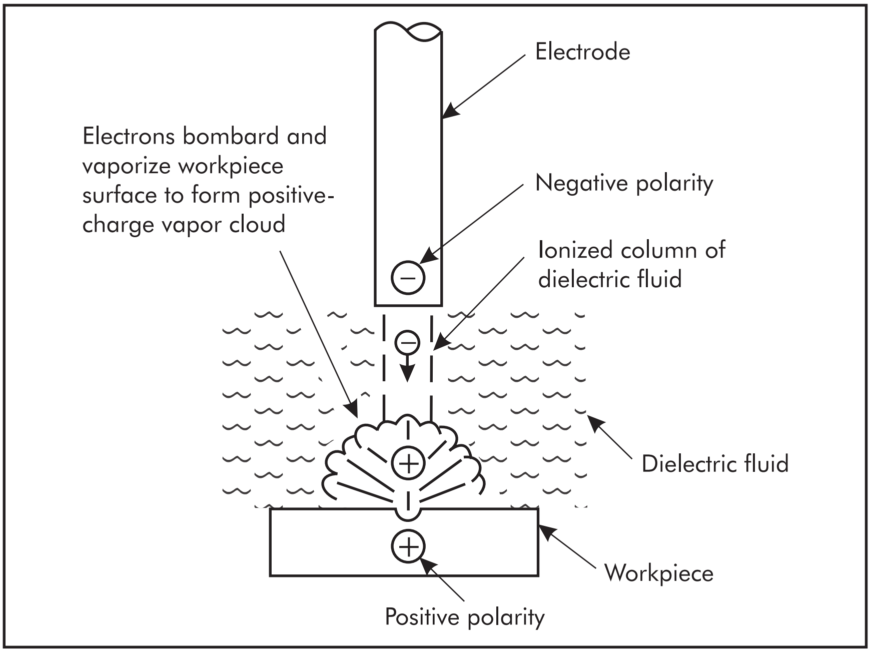


Figure 3-14. Electron bombardment produces vapor cloud.

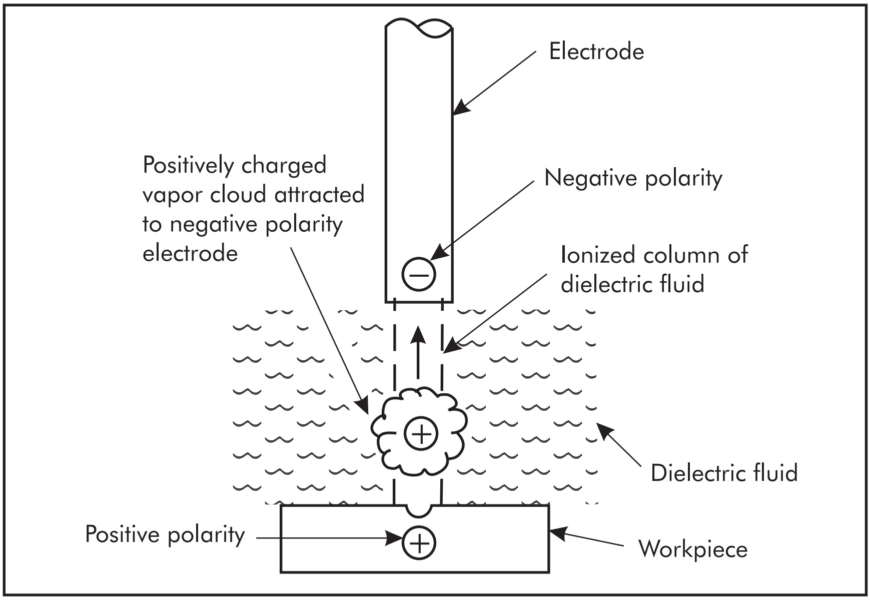


Figure 3-15. Positive vapor cloud attracted to negative electrode.

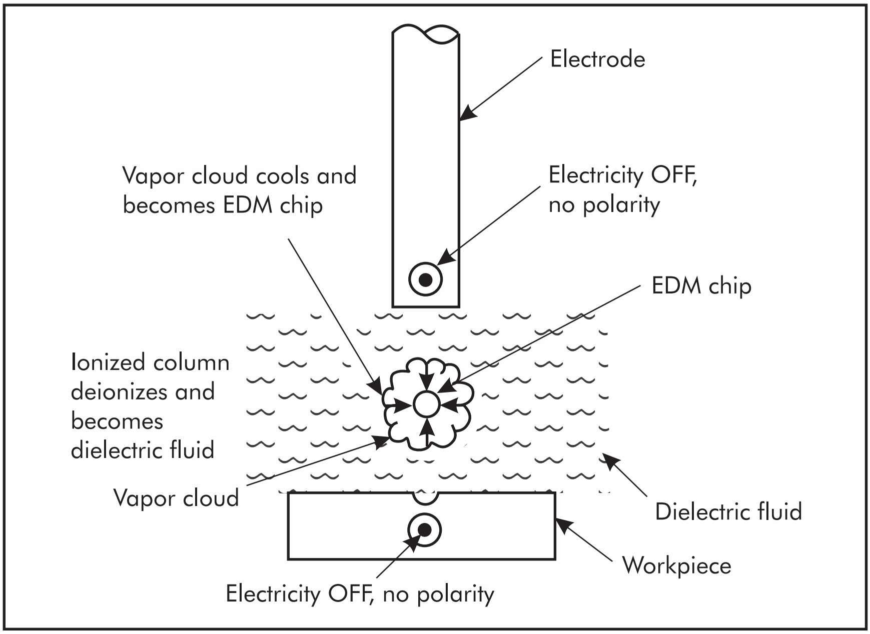


Figure 3-16. Spark OFF, vapor cloud cools to form chip.

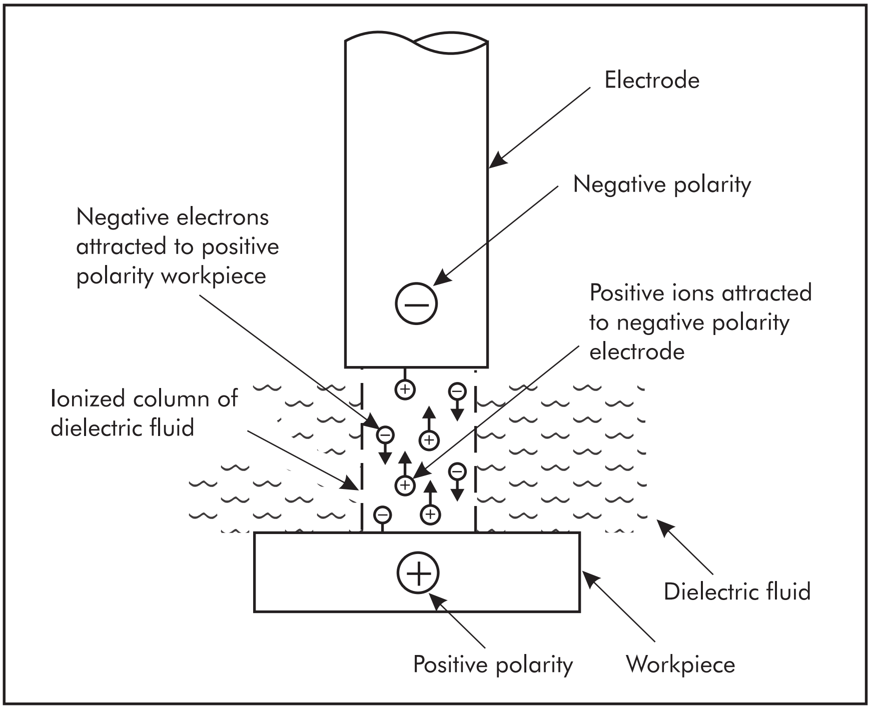


Figure 3-17. Electron and positive-ion movement with negative electrode polarity.

bombardment causes the surface materials of both the electrode and workpiece to be vaporized with each spark. Figures 3-18 through 3-21 illustrate this bombardment, the vapor clouds, and the EDM-chip formation.

The weight of a positive ion, consisting of the atom nucleus and remaining electrons, is thousands of times greater than the weight of an electron. Since the positive ion has such a heavy weight, it accelerates much slower than the electron. Fewer positive ions than electrons arrive at the bombardment surface during sparking, which is why electrons are considered the primary source of energy for EDM material removal.

Vapor-cloud material from both the electrode and workpiece is present in the ionized-dielectric-fluid column. These vapor clouds are opposite polarities, so they are attracted to each other. The vapor clouds combine, and when sparking electricity is turned OFF, they cool to form

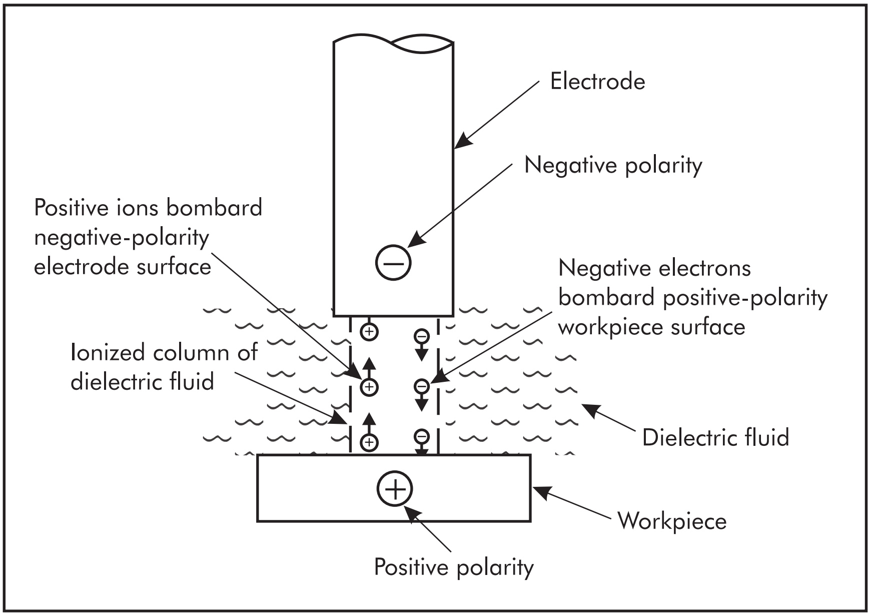


Figure 3-18. Electron and positive-ion bombardment.

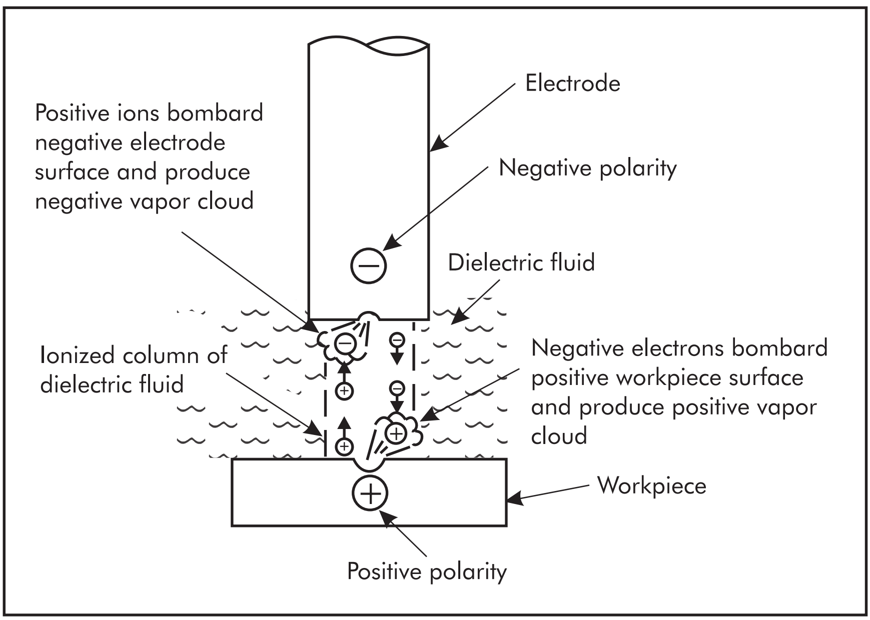


Figure 3-19. Electron and positive-ion vapor clouds.

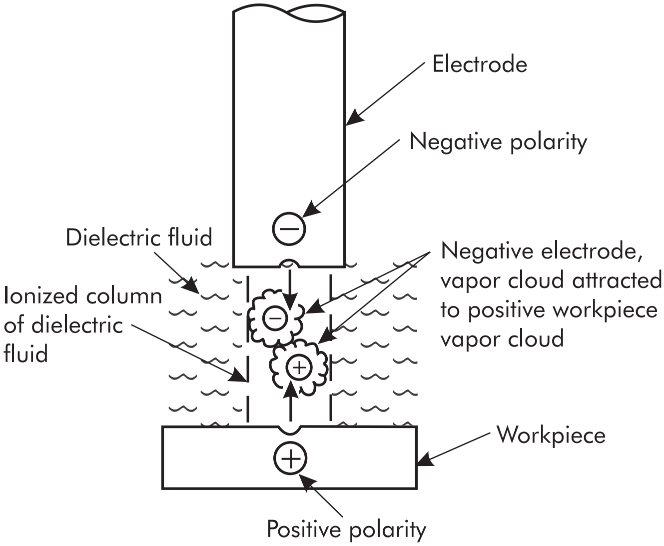


Figure 3-20. Opposite-polarity vapor clouds attract.

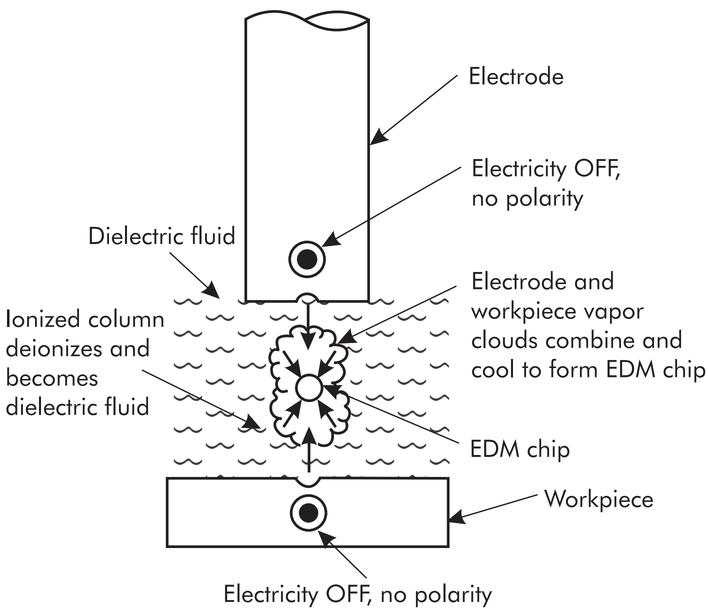


Figure 3-21. Vapor clouds combine and cool to form EDM chip.

an EDM chip. Thus, the EDM chip contains material from both the electrode and the workpiece. As the chip vapor cools, it forms into a hollow sphere, which is the characteristic shape produced by a solidifying vapor.

It is possible to use either negative or positive electrode polarity for machining with most die-sinker machines. Illustrations, to this point, have shown negative electrode polarity and electron bombardment of the workpiece for material removal. EDM researchers have determined that positive electrode polarity is useful for reducing electrode wear or providing more stable servo operation when using certain electrode and workpiece materials. Figure 3-22 illustrates material removal using positive electrode polarity by means of positive-ion bombardment.

Positive electrode polarity usually removes workpiece material at a lower rate than negative electrode polarity. However, positive electrode polarity reduces wear of copper and graphite electrodes when settings recommended by the machine manufacturer are used for spark control.

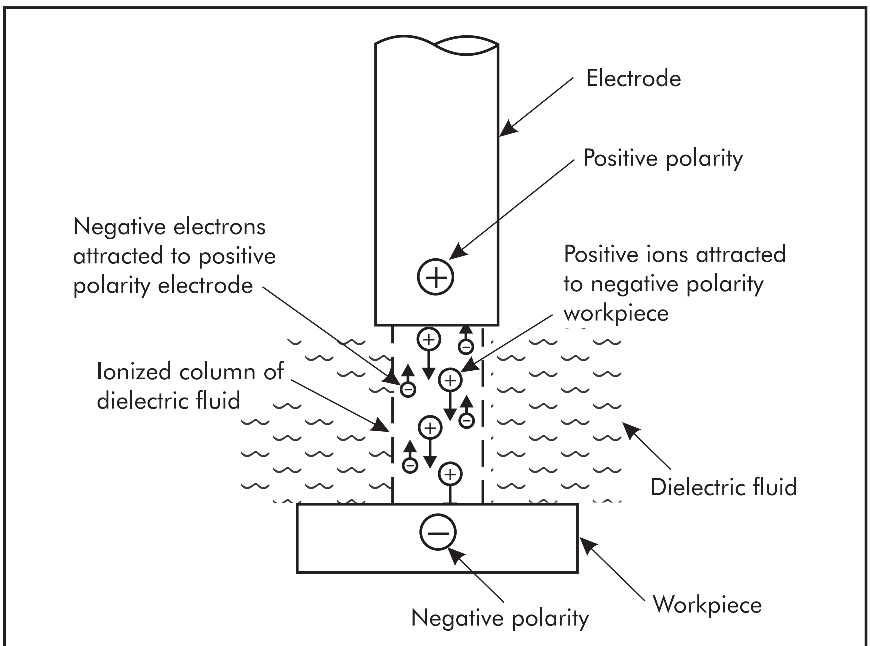


Figure 3-22. Material removal with positive electrode polarity.

Wire-cut machine electrode polarity is rarely changed and should only be done based on the recommendation of the machine manufacturer. Some wire-cut machines do not include the option of changing the electrode polarity. Wire-cut-machine manufacturers will normally provide the electrode polarity that produces the maximum material-removal rate, since electrode fabrication and material costs are not a primary factor in machining operations.

The dielectric strength of the deionized water must be carefully considered for wire-cut-machining operations. The machine must be operated only within the allowable range of water quality, as specified by the manufacturer. Should the water be allowed to become conductive, it will not ionize properly. This will have a detrimental affect on servo stability and metal removal rate. The water's dielectric strength changes as the deionized water passes through the sparking area. Reusing the deionized water, without filtration and reprocessing through the deionizing resin bed, is not recommended.

Special attention should be given to the unwanted electrical machining of the workpiece during times when the workpiece is allowed to dwell and the sparking electricity remains ON. Under normal machining conditions, the electrode wire is continually passing through the workpiece that is traversing to produce the required shape. As the sparks from the electrode wire machine the workpiece, a slot is produced. The length of the spark is controlled by the dielectric strength of the fluid. Should the workpiece be allowed to stop the traverse and dwell in one location while sparking electricity is ON, a line will be machined into the workpiece surface. The reason for this machining may be explained by comparing the spark length during the machining and during the dwell period of the workpiece.

Figure 3-23 illustrates the slot produced by sparking during normal machining. Under the conditions illustrated, ionization of the dielectric fluid will produce the same spark length for the frontal and radial overcuts, because the workpiece's traverse rate is adjusted to produce the highest sparking efficiency. To accomplish this, the spark gap is maintained at a slightly smaller dimension than normal, due to the movement of the workpiece toward the electrode. Should the traverse be stopped and the workpiece be allowed to dwell at one location with the sparking electricity ON, the spark length would extend to the normal machining length, resulting in a line machined into the workpiece surface. Figure 3-24 illustrates this point.

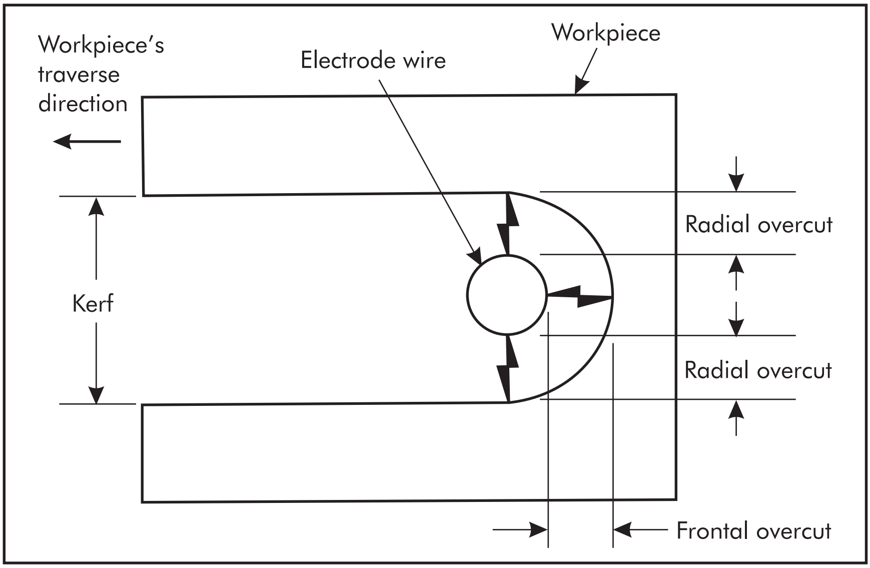
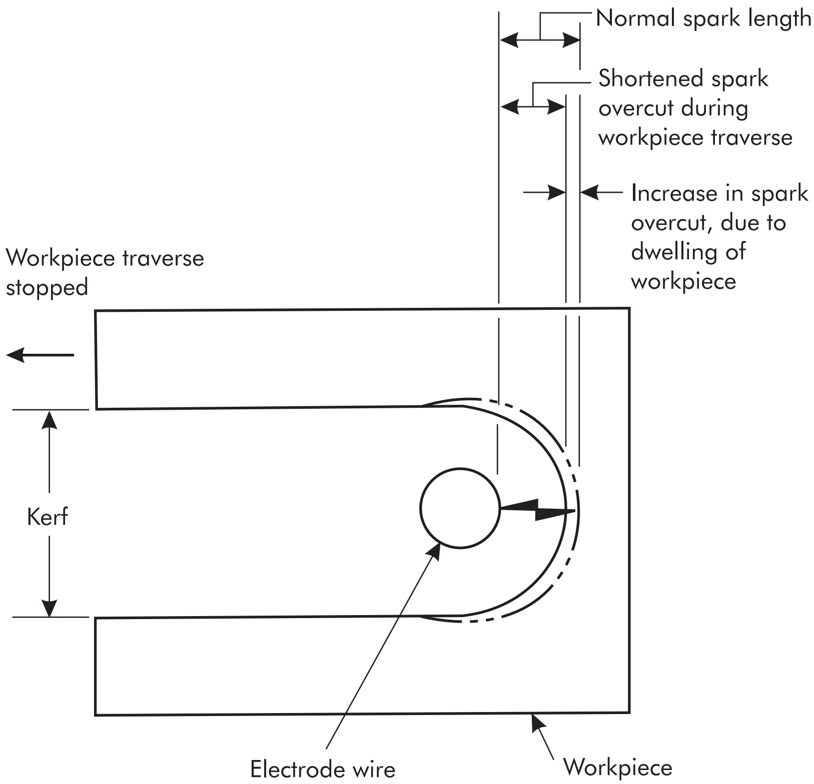


Figure 3-23. Wire-cut slot produced during normal machining.

Enlargement of the slot at the point of workpiece dwell is explained by the ionization point of the dielectric fluid. There is a dimension between the electrode and workpiece at which the dielectric fluid ionizes and a spark occurs. During normal wire-cut machining, the spark length is slightly compressed due to the traverse rate of the workpiece. The workpiece's traverse rate is adjusted to ensure that material is always presented to the electrode for efficient sparking. When the traverse is stopped and the workpiece is allowed to dwell in one place with the sparking electricity ON, the sparking continues until the spark length extends to the normal overcut dimension. This causes an enlargement to the spark overcut at the point where dwelling of the workpiece has taken place. This enlargement, although very small in depth, appears as a machined line in the workpiece surface.

Radial overcut is slightly reduced while the workpiece is being traversed. The speed of traverse reduces the time the slot walls are exposed to sparking, which causes a small reduction in the radial overcut dimension, as compared to normal spark overcut. When workpiece traverse is stopped with the sparking electricity ON, sparking continues and machines both the frontal- and radial-overcut areas to the normal spark-length overcut dimension.



Conditions:
- Electrode wire continuously passing through workpiece
- Workpiece traverse stopped
- Dielectric fluid surrounding electrode wire and filling kerf slot
- Sparking electricity ON

Figure 3-24. Increase in overcut with traverse stopped and sparking electricity ON.

The EDM Sparking System 4

SPARKS OCCUR BETWEEN THE CLOSEST POINTS

A characteristic of electricity is that it flows along the shortest path available. This characteristic is important when applied to the fundamentals of Electrical Discharge Machining (EDM).

The sparking surfaces of the electrode and workpiece may appear to be very smooth when examined visually. In reality, these surfaces are made up of many very small irregularities. These irregularities consist of peaks and valleys. When the electrode and workpiece are at the proper separation distance for sparking to occur, the peaks of the electrode and workpiece surfaces extend above the valleys and become the points where sparking will occur. There will be one electrode peak and one workpiece peak that are closer together than all of the other remaining electrode to workpiece peaks. Since these particular electrode and workpiece peaks have the shortest distance between them, and electricity flows across the shortest distance, a spark will occur at this peak-to-peak point. Figure 4-1 illustrates the spark occurring between the closest electrode-to-workpiece peaks.

MOVEMENT OF SPARK OVER ELECTRODE SURFACE

From Figure 4-1, it appears that the electrode and workpiece surfaces are quite coarse. In fact, all surface finishes have irregular surfaces. Even though the surfaces have only very minute peaks and valleys, these very small changes of dimension allow the EDM spark to occur between the closest peaks and to have the next spark occur at another location.

Spark movement is based on material being removed from the electrode and workpiece as each spark occurs. The material that is removed

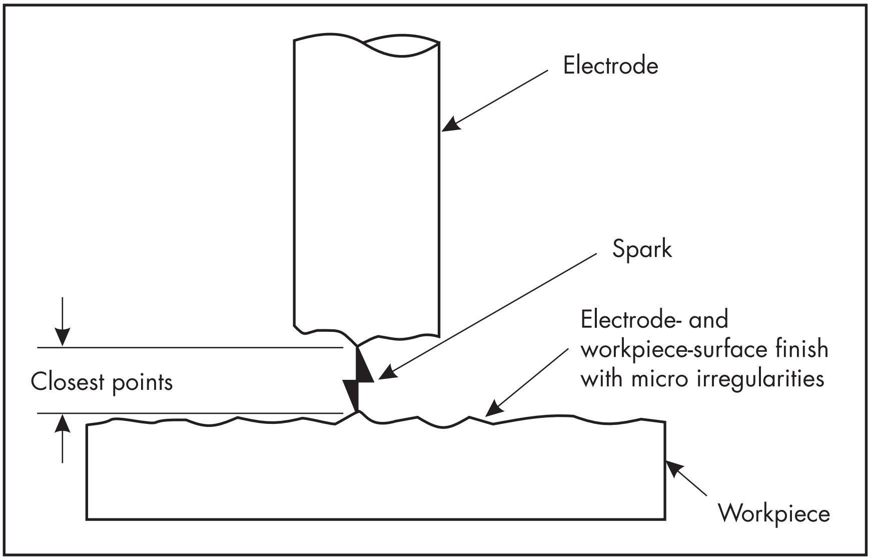


Figure 4-1. Spark occurs between closest points.

reduces the height of peaks and increases the distance between the electrode and workpiece surfaces at that particular location. The location where a spark occured no longer has the "closest peaks" between the electrode and workpiece surfaces. As a result, another electrode-to-workpiece peak becomes the next "closest point," causing the next spark to occur at that location. Consequently, the spark location changes with each spark. This EDM condition is illustrated by Figure 4-2.

TYPES OF EDM-POWER SUPPLIES

EDM machines use different kinds of sparks depending on the electronic circuitry provided. Sparking is normally produced by one of two types of EDM-power supplies:

- resistor-capacitor power supply, and
- pulse-power supply.

The sparks produced by the resistor-capacitor (R-C) and the pulse-power supply are quite different. The difference is not visually apparent

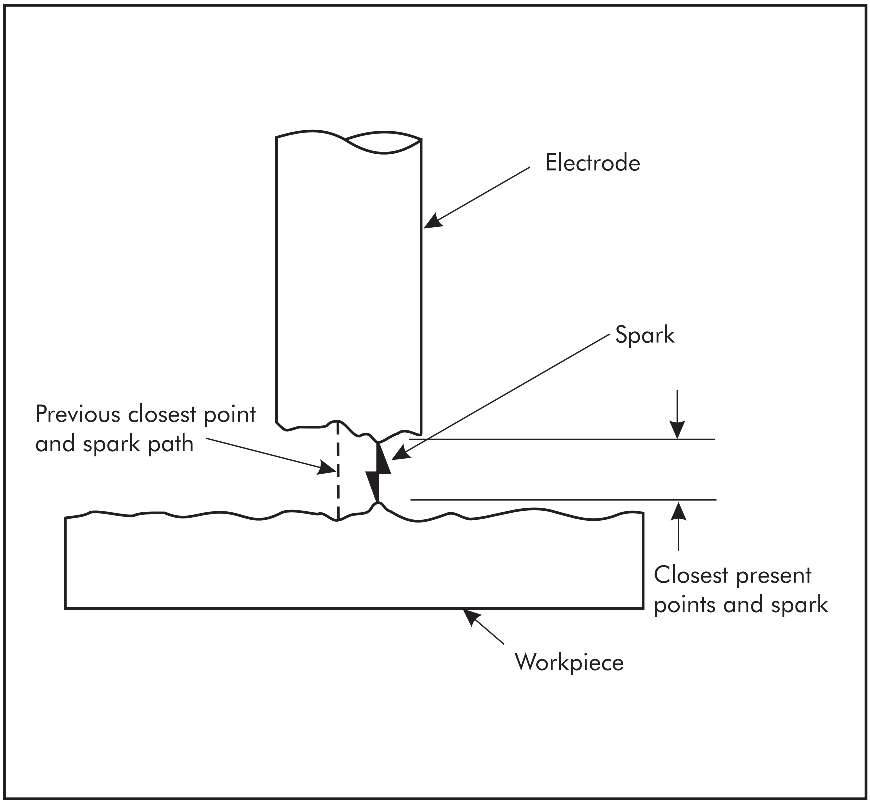


Figure 4-2. Spark movement with a change of closest points.

by observation of the electrode to workpiece sparking. When considering the fundamentals of Electrical Discharge Machining, it is only important to develop a mental picture of what a spark looks like as it occurs. From a technical standpoint, this mental picture is similar to looking at the image of a spark as seen on an oscilloscope. The spark image is known as a *waveform*, and it allows the design engineer to describe the spark type being used.

Descriptions of waveforms for the R-C- and pulse-power supplies are described in detail in the EDM generator text. At this point, however, it is sufficient to say that the R-C power-supply waveform is more complex than the pulse-power-supply waveform. For the purpose of creating a mental picture, the pulse-power-supply waveform is used because it is quite simple to understand.

PULSE-POWER-SUPPLY WAVEFORM

The pulse-power-supply waveform is like a picture of what takes place when the spark is turned ON and then OFF. EDM designers refer to this as "spark-ON time and spark-OFF time." Since electronic diagrams may seem complicated and difficult to understand, the simple procedure of turning a light bulb ON and OFF can be used to illustrate a spark-ON and -OFF waveform. This action is illustrated by Figure 4-3.

When entering a room, it is normal to reach out and turn a light switch ON. When leaving the room, the switch is turned OFF. This is an accepted procedure and little thought is given to the way an electrical engineer would describe this action. An engineer might describe this through the use of a waveform picture or drawing. The waveform would be very much the same as if the engineer was viewing the display on an oscilloscope. This *waveform* would show the engineer what events occurred and the order in which the events occurred. These characteristics are:

- the point that the switch is turned ON;
- the time required for the electrical current to rise to the maximum value;
- the time that the electric current remains ON at the maximum value;
- the point that the electric current is turned OFF;
- the time it takes for electricity to stop flowing; and
- the total time it takes from turning the switch ON until the electric current stops flowing.

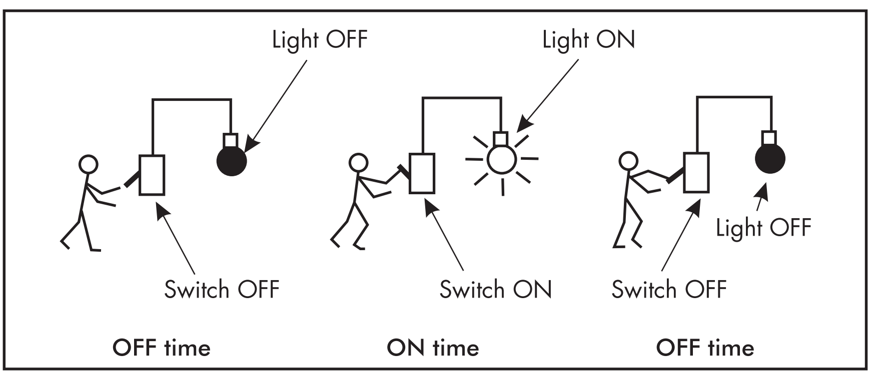


Figure 4-3. Electric light demonstrates spark-ON and -OFF time.

This may appear complicated, yet all of these events may be presented in a simple square-wave diagram or in a waveform picture. Figure 4-4 illustrates this type of waveform, based on the action of turning a light bulb ON and then OFF.

The waveform is drawn as a graph. The horizontal reference line indicates that no electric current is flowing. The vertical reference line represents a zero-time reference. At some point, the light switch is turned ON. At that time, the electric current starts to flow to the light bulb. The vertical line, originating at the "switch closed" point, represents this time. In this instance, the vertical line is drawn perpendicular to the zero-reference timeline. In reality, this line would not be exactly perpendicular to the zero-electric-current-flow line, since a very small amount of time is required for the electric current to go from zero to the operating level point. This time is so short that it is not shown for this illustration.

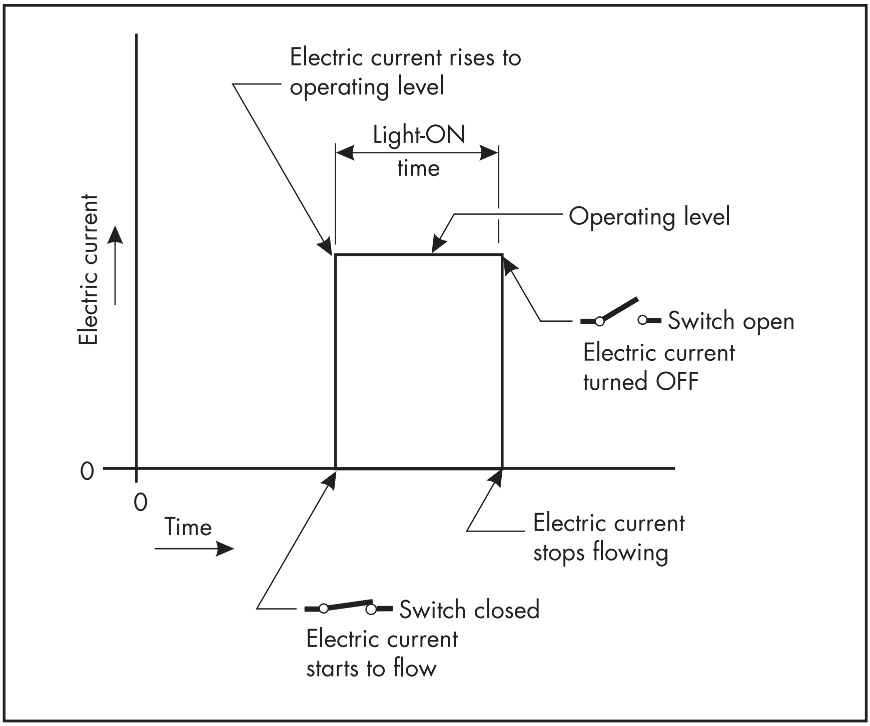


Figure 4-4. Waveform showing light-ON time.

Once the electric current rises to the operating level, it remains there until the light switch is turned OFF. Simply put, the light remains ON until the light switch is turned OFF. This time period is represented by the horizontal line above the zero-electric-current-flow line and is called the "operating level." Next, the switch is turned OFF. The electric current then returns to zero and the light is turned OFF. Again, a small amount of time is required for the electric current to go from the operating level to zero. This time is so short that it is not shown for this illustration.

When viewing the waveform that shows the turning of a light bulb ON or OFF, a square or rectangular diagram is used. This waveform shape is described as a *square wave* and it is the typical waveform for a pulse-EDM power supply.

EDM-SPARK-ON AND -OFF TIME

Turning an electric light bulb ON and OFF correctly describes a square waveform, but it does not completely describe the EDM-sparking condition. It is highly possible that a room light will remain ON for a long period of time before being turned OFF. This is not a desirable condition for EDM sparking. In fact, EDM sparking requires that the spark be turned ON and OFF thousands of times per second. This turning ON and OFF of the EDM spark is normally accomplished through the use of controls provided at the EDM-power-supply control panel.

Spark-ON and -OFF time is set in microseconds. One microsecond is equal to one-millionth of a second. The normal setting range for spark-ON and -OFF time is from 1 to 250 microseconds. Based on using an equal time setting for both ON and OFF time, this ON- and OFF-time range will produce the potential for sparking in a range of from 2,000 to 500,000 sparks per second.

DIRECT-CURRENT (DC) SPARKING

The light bulb illustration must also be clarified with regard to the kind of electricity used for EDM sparking. Most residential light bulbs use alternating-current (AC) electricity for lighting bulbs. *Alternating*

current (AC) describes electric current that flows in two directions. It alternates in the direction of flow. First, it flows in one direction for a given period of time. It then reverses and flows in the opposite direction for an equal period of time. In this way, the flow of electric current "alternates" from one direction to the other in equal time periods. AC electricity is not suitable for EDM sparking.

The EDM-sparking-electrical circuit uses direct-current (DC) electricity. DC electricity always flows in only one direction. An illustration of DC-electricity flow is where electricity is supplied from a battery to a flashlight. Figure 4-5 illustrates a flashlight's electrical circuit, with the DC electricity provided by a battery.

The light bulb in a flashlight may be turned ON or OFF with the action of a switch. When the switch is actuated, the bulb lights and remains ON until the switch is turned OFF. During the time the switch is actuated and the light bulb is ON, electricity continuously flows from the battery to the bulb, and back to the battery. This electricity is DC, since it only flows in one direction. In the flashlight's electrical circuit, the battery is the source of the electric current. The battery may then be considered as the DC-power source.

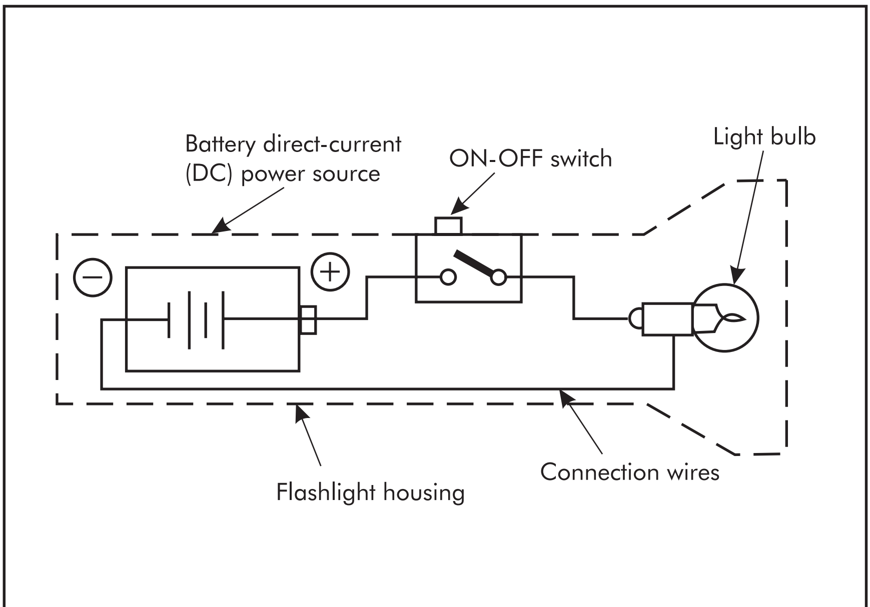


Figure 4-5. Flashlight's DC-power source and ON-OFF electrical circuit.

ELECTRICAL CIRCUIT FOR EDM SPARKING

The electrical circuit that provides electricity for EDM sparking is very similar to the DC flashlight's electrical circuit. Figure 4-6 illustrates the basic electrical circuit for EDM sparking.

The basic EDM-sparking-circuit components can be directly compared to the flashlight's electrical components, as shown in Table 4-1.

Table 4-1. Comparison of EDM-sparking-circuit components

Flashlight	EDM Sparking System
Battery	DC power source
Switch	Electronic ON-OFF switch
Lamp	Spark

The components used in the EDM-sparking system are not readily apparent when viewing an EDM machine. The DC-power source is normally contained within the machine's electronic assembly. The electronic ON-OFF switch is also contained inside of the electronic assembly, except that the controls for setting ON and OFF time are available to the machinist as part of the machine's control panel. Electrical cables are included between the electronic assembly, the electrode, and the workpiece for conveying the spark electricity from the electronic assembly to the sparking gap. The sparking electricity then flows from the DC-power source through the electronic switch, the electrode, the sparking gap, and the workpiece, then back to the DC-power source.

EDM-DC-POWER SOURCE

The DC-power source is an assembly of electrical and electronic components. The DC-power source is not a battery, but an electrical assembly that changes AC electricity to DC electricity. The DC electricity is then used to produce the EDM spark. Figure 4-7 illustrates a simplified DC-power source, used for producing the DC electricity for EDM sparking.

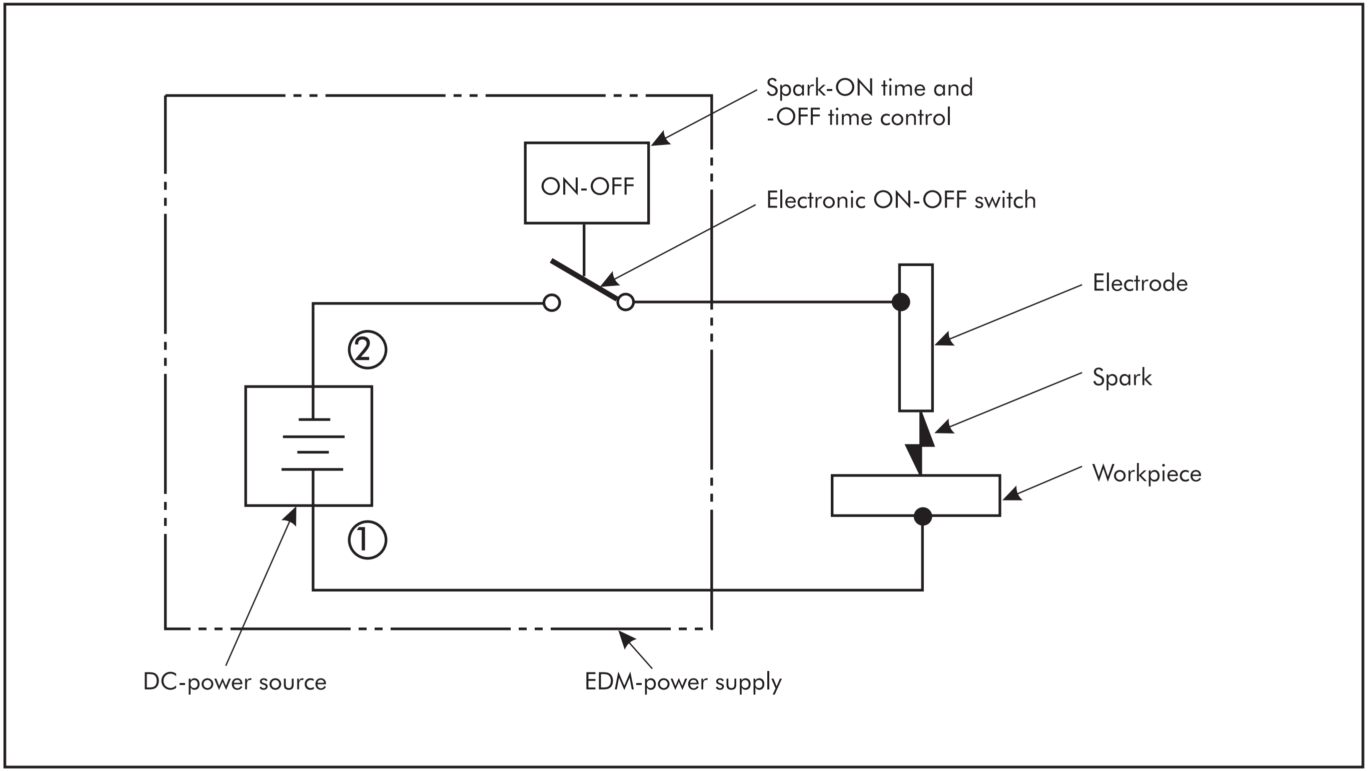


Figure 4-6. The EDM-sparking-system electrical circuit.

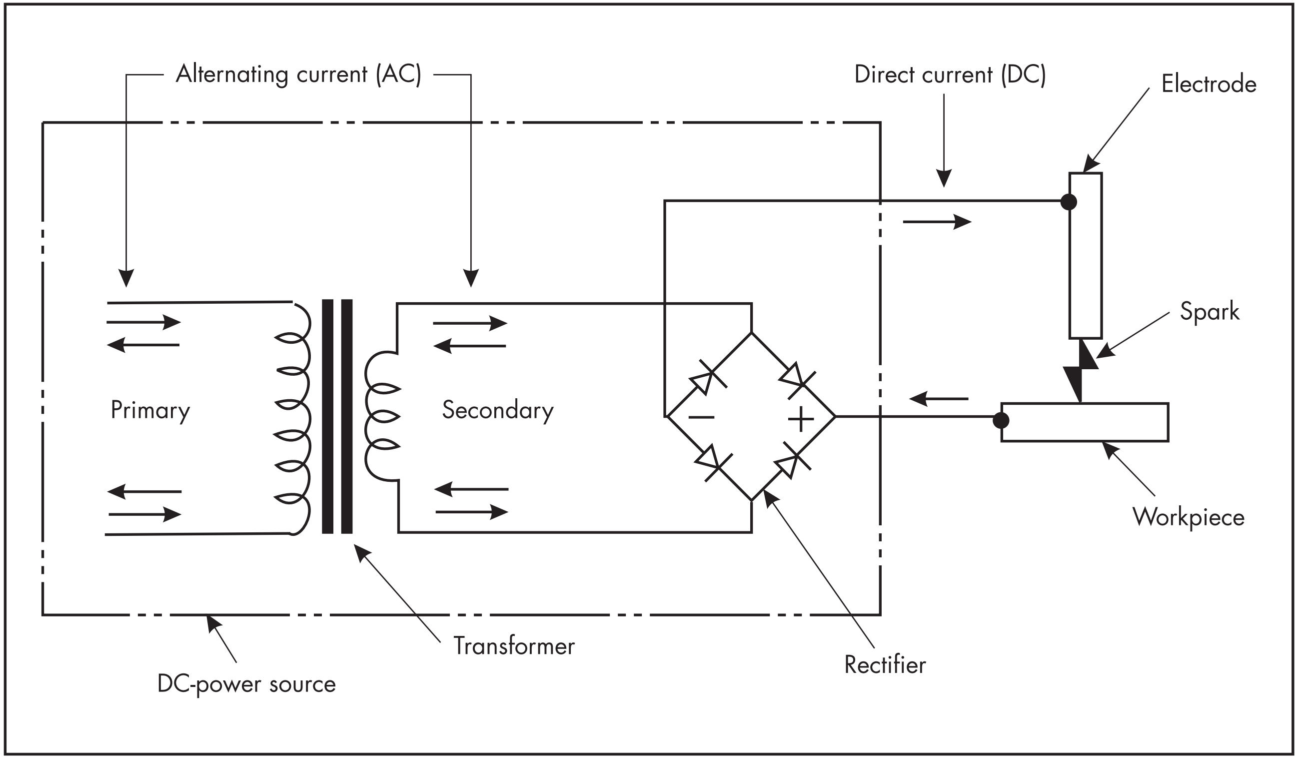


Figure 4-7. Simplified DC-power-source electrical circuit.

The simplified DC-power source electrical diagram does not illustrate all of the electrical and electronic components required to produce the DC electricity for the spark. Only the very basic components are shown. Operation of the electrical circuit is described in the following sections.

TRANSFORMER

The *transformer* is an electrical device that changes or "transforms" AC electricity. The transformer for the DC-power source consists of two coils that are wound on a magnetic core. The two wound coils are separate from each other. One is known as the primary winding and the other as the secondary winding. The primary winding is normally connected to the higher voltage available within the electronic assembly. The secondary winding is designed to produce the voltage required to operate the DC-power source and the EDM-sparking circuit. Electricity from the transformer is AC and is not suitable for the sparking circuit until it has been rectified.

RECTIFIER

Alternating-current electricity from the transformer is applied to an electrical device known as a *rectifier*. An electrical rectifier allows electricity to only flow in one direction. The result is that the AC electricity that is applied to the rectifier is changed from AC to DC as the electric current flows through the rectifier. The DC electricity supplied by the rectifier is used for the EDM-sparking circuit.

The transformer and rectifier are the basic components of the EDM-DC-power source and they serve the same purpose as the battery in a flashlight's electrical circuit. The purpose of these components is to supply electrical energy for the spark. It must be noted that, while the EDM-DC-power source may be compared to a battery, it does not wear out and require replacement in the same manner. DC-power-source components occasionally fail and need to be replaced, but the operational life of the assembly is the same as that of the EDM-power-supply assembly. The DC-power source is specially designed to suit the needs of each individual model of EDM-power supply.

SPARK-ON/OFF-TIME WAVEFORM

It is possible to graphically illustrate what the electrical output of the flashlight or the EDM-power source looks like as the electrical ouput is switched ON and then OFF. Figure 4-8 illustrates the square waveform that is developed as the EDM-power-source electricity is turned ON and OFF with the electronic switch.

The spark's square waveform is characteristic of pulse-EDM-power supplies. The electronic switch turns the sparking energy ON and OFF very precisely. Both ON time and OFF time are set in microseconds.

As the illustration shows, the electronic switch turns ON the sparking electricity. The electricity increases to a maximum height and remains at this height until it is turned OFF. At the turn-OFF point, the electricity reduces very rapidly to zero and the spark is terminated. During the spark-OFF time, no electricity is flowing. The spark waveform then takes the shape of a rectangle and gives the appearance of a square wave.

There is one very important difference when comparing the flashlight's electrical circuit to the EDM-sparking circuit. The flashlight bulb will turn ON and then OFF each time the switch is actuated, as long as the battery is in good condition and the lamp has not failed. Sparking does not occur in an EDM circuit simply because the electronic switch is actuated. Should the spacing between the electrode and the workpiece be larger than the normal sparking gap, ionization of the dielectric fluid will not take place, and no spark will occur. Figure 4-9 illustrates missing sparks caused by the absence of dielectric fluid ionization.

SPARK FREQUENCY

ON time and OFF time for an EDM-power supply is normally set in a range from 1 to 250 microseconds. Figure 4-10 shows the normal spark frequency range of EDM-power supplies based on equal spark-ON/OFF microsecond timing. Using these ON and OFF times, the spark frequency range is 2,000 sparks-per-second to 500,000 sparks-per-second (see Equation 4-1).

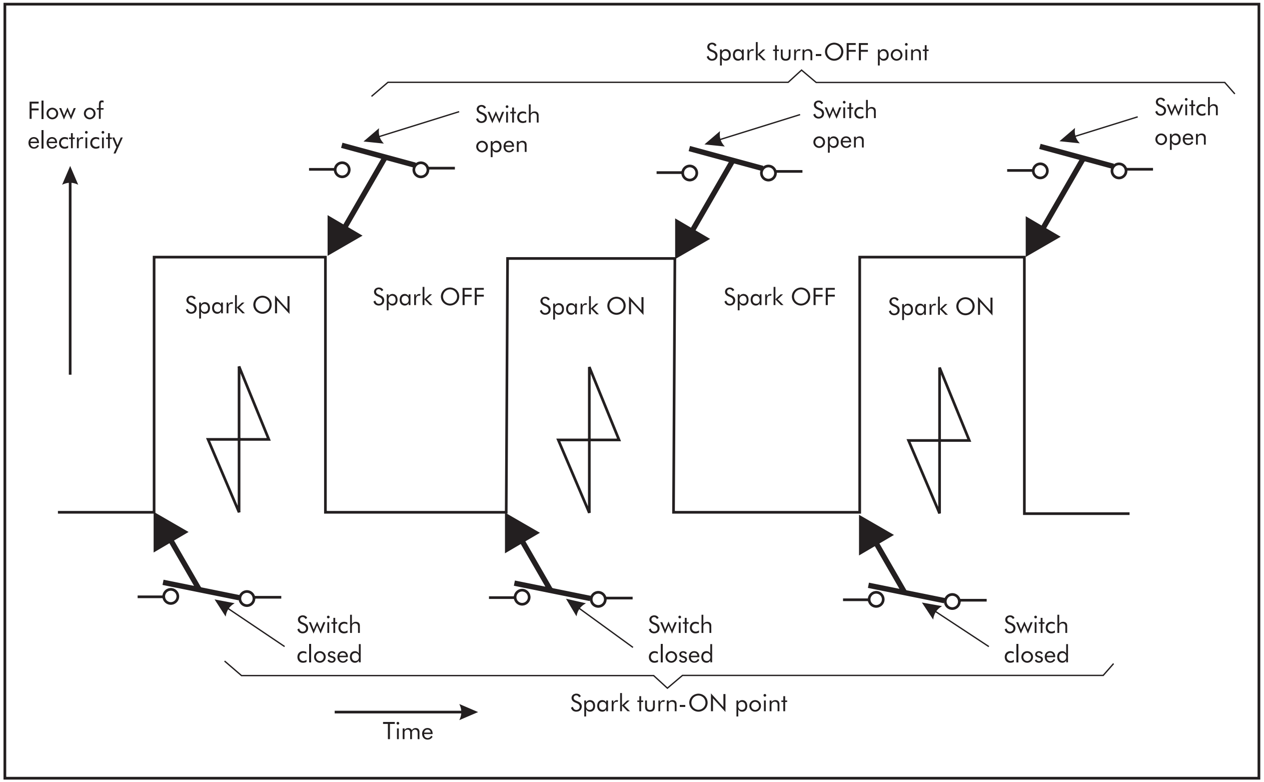


Figure 4-8. Electronic switch develops spark-ON-OFF square waveform.

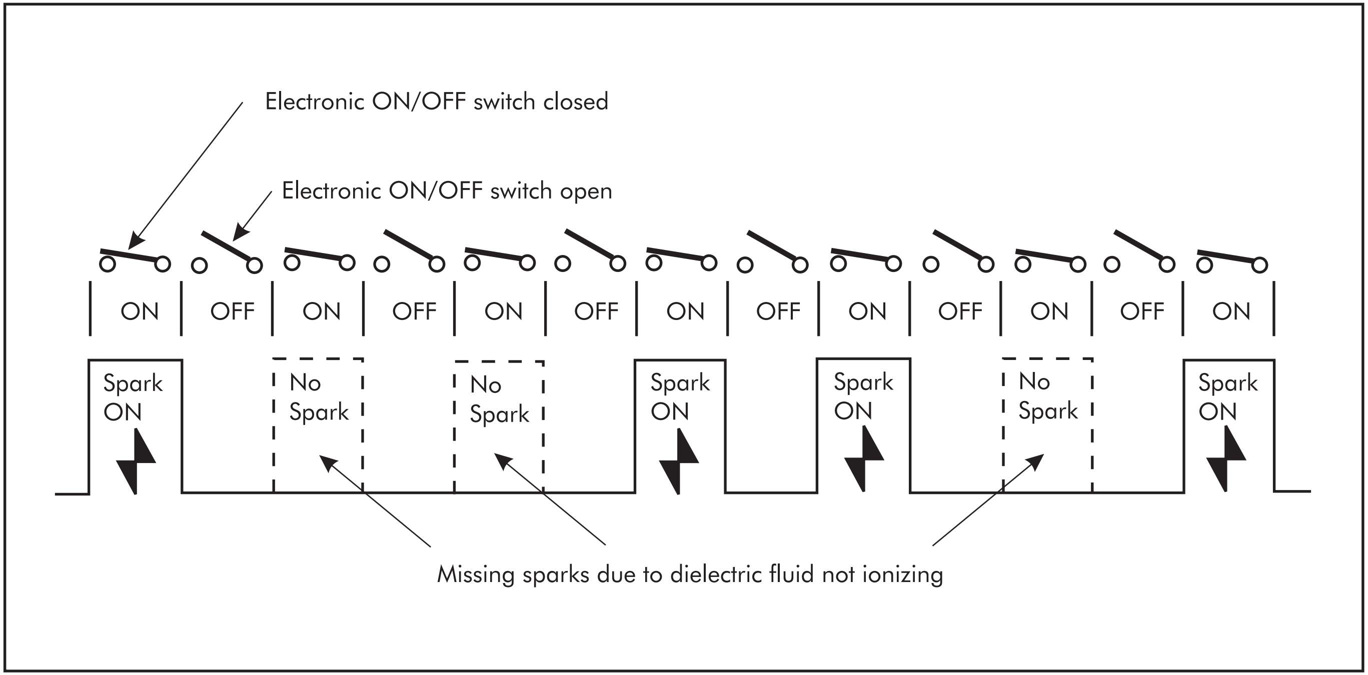


Figure 4-9. Dielectric-fluid ionization determines spark occurrence.

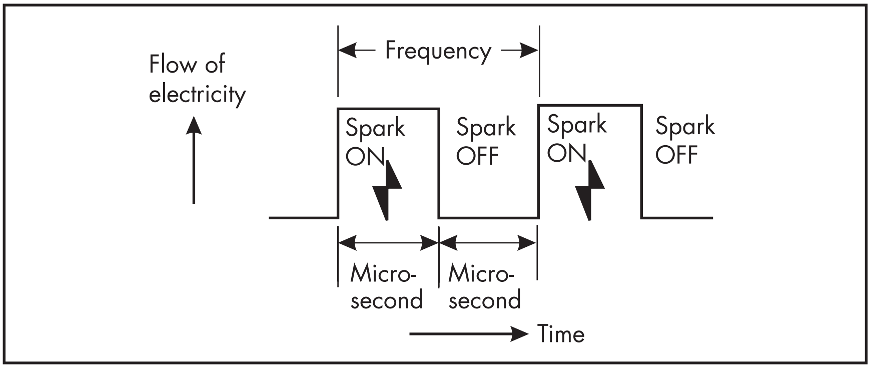


Figure 4-10. ON and OFF times determine spark frequency.

$$F = \frac{1,000,000}{ON + OFF} \tag{4-1}$$

where:

F = frequency (sparks per second)
ON = spark-ON time (microseconds)
OFF = spark-OFF time (microseconds)

Spark frequency based on: 1-microsecond ON, 1-microsecond OFF

$$F = \frac{1,000,000}{1+1}$$

$$F = \frac{1,000,000}{2}$$

$$F = 5,000,000$$

Spark frequency based on: 250-microseconds ON, 250-microseconds OFF

$$F = \frac{1,000,000}{250+250}$$

$$F = \frac{1,000,000}{500}$$

$$F = 2,000$$

The illustration is based on the ON and OFF times being equal. This is a condition that almost never exists. In most instances, the spark-ON

time and -OFF time will be different. Data supplied by the EDM-machine manufacturer should always be used to set the spark-ON/OFF time.

Spark frequency will affect the available sparking-ampere output from the EDM-power supply. As frequency increases, sparking-ampere output will decrease. This does not normally present a problem since low spark frequencies are used for roughing operations and maximum sparking amperes are available at these frequencies. High spark frequencies are normally used for finishing operations where fine surface finish is desired. Finishing is normally accomplished at low sparking amperes.

Some of the early die-sinker machines that used vacuum tubes had controls only for setting spark frequency. These early machines did not include a spark-ON/OFF control and were very limited in their ability to control the spark. Spark frequency for such machines was within an approximate range of 20–150 kHz.

The EDM-power Supply (Generator) 5

This chapter describes the main components of EDM-power supplies and the two types that can be used—electronic-switch ON/OFF or resistor-capacitor (R-C).

THE POWER-SUPPLY ASSEMBLY

The EDM-power supply is the center of any EDM operation. Depending on the country where it is made, EDM manufacturers call this unit a *power supply* or a *generator.* US manufacturers prefer the term "power supply," while those manufacturers outside of the US prefer to use the term "generator." Regardless, these words refer to the same assembly that provides identical functions. In this book, "power supply" designates the assembly.

The power-supply assembly contains subassemblies for the DC-power source, servo control, AC-electric-power distribution and DC-arc protection. This chapter deals with only the DC-power source and operating controls, since these subassemblies are primarily used for spark control. Other subassemblies are discussed in later chapters.

A basic knowledge of electrical terms—such as volts, voltage, amperes, peak amperes, average amperes and duty cycle— is vital to understand the way a spark is controlled. It is not necessary, however, to have electrical or electronic knowledge or experience to understand the meaning of these words as they relate to how the EDM-power supply produces sparks.

SPARK-ON AND SPARK-OFF TIME

Spark-ON and spark-OFF-time controls are included in the power-supply assembly. These controls may be in the form of knobs or dials, with particular set points or with a computer-video display with input

from a computer keyboard. Settings are in microseconds and the actual time settings used for ON and OFF times are usually different. Manufacturers provide data for spark-ON and -OFF settings for each machine. The ON/OFF controls set the timing for the electronic switch that turns the sparking power ON and OFF. This electronic switch is sometimes called an *oscillator*, or an electronic circuit used to generate a periodic-output pulse of a duration set by the spark-ON/OFF controls.

SPARKING-POWER OUTPUT

The electronic switch allows pulses of electricity to flow in one direction, with a space between each pulse. During the ON time, each pulse is the source of energy for a spark. Sparking power for an EDM pulse is described as a *pulsating-direct current (DC)*.

Power output for the EDM-power supply comes from the DC-power source, which is one of the subassemblies within the power supply's main assembly. Power output for EDM-power supplies is rated in amperes. The amperes available for most EDM-power supplies range from 1–400 A. The ampere output indicates the material-removal capabilities of the power supply. As amperes increase, material-removal rates also increase and the surface finish becomes coarser.

VACUUM TUBE TO TRANSISTOR EVOLUTION

The original pulse-type-power supplies used vacuum tubes. These early vacuum tubes were a source of concern because each had a filament for heating the cathode that produced the electricity required for the spark. The filament, comparable to that of an electric light bulb, often failed, requiring frequent tube replacements. With the advancement of electronics, solid-state devices replaced the vacuum tubes. This greatly improved the system's reliability. Figure 5-1 illustrates a basic electrical diagram for a transistor sparking circuit.

When an electronic signal from the switch control turns the transistor ON and OFF, it causes the transistor to act like an electronic switch that can be opened or closed. During spark-ON time, the transistor is closed to let electricity flow from the DC-power source to the electrode, across the sparking gap to the workpiece, and then back to the

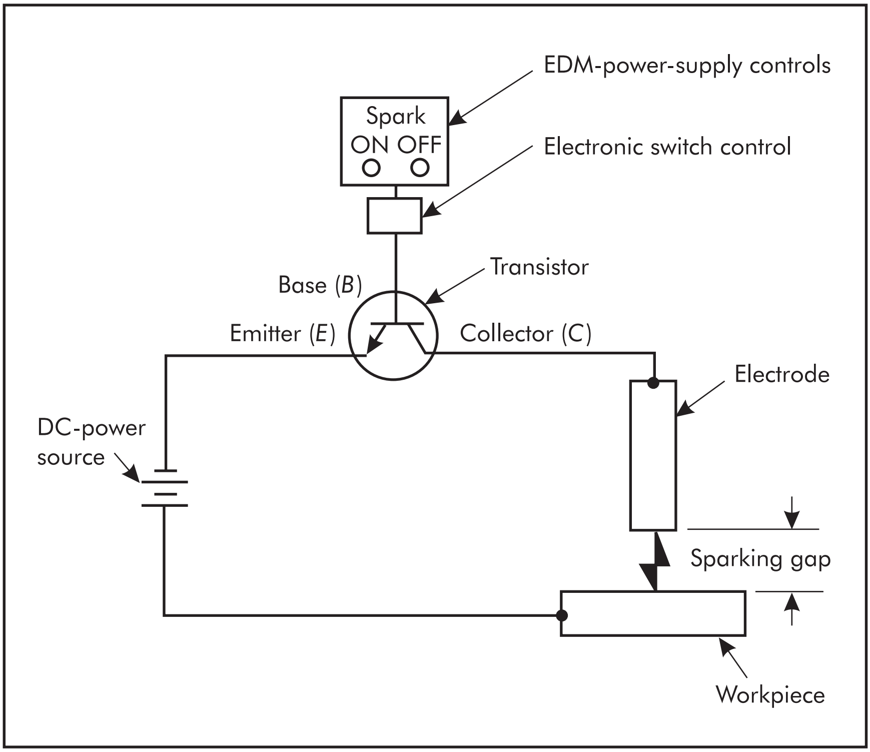


Figure 5-1. Basic transistor sparking circuit.

DC-power source. During the OFF time, the transistor is open, stopping the flow of electricity. Spark-ON and -OFF times are set by the EDM-power-supply controls, either manually or, if a CNC-controlled machine, by computer program.

AMPERES

EDM-power-supply transistors, located in the DC-power-source subassembly, control sparking electricity. The amount of sparking electricity here is measured in amperes. Each transistor allows a certain number of amperes to flow in the sparking circuit. Figure 5-2 shows how the addition of parallel transistors increases sparking amperes.

In Figure 5-2, each of the three transistors has the capability of supplying 10 A of sparking electricity. Two of the transistors may be added

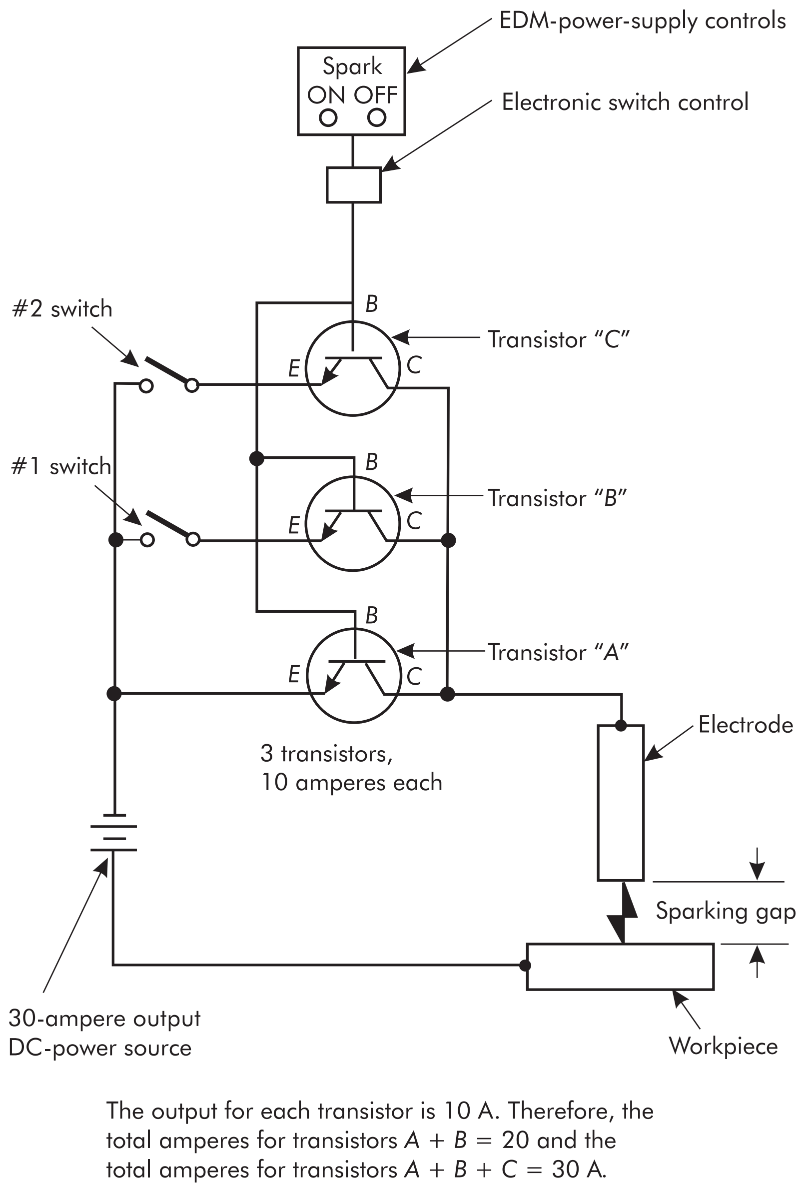


Figure 5-2. Addition of transistors to increase sparking amperes.

or removed from the circuit with switches that are labeled #1 and #2. The remaining transistor is always connected to the sparking circuit, since no switch is provided for this transistor.

Sparking amperes with only one transistor in the circuit are 10 A. When switch #1 is closed and the second transistor is added to the circuit, the sparking electricity is increased to 20 A. When switch #2 is closed, the third transistor is added to the circuit and the sparking amperes are increased to 30 A.

INCREASING SPARKING-OUTPUT POWER

A square-wave diagram shows the change in sparking amperes as transistors are added to the sparking circuit. Figure 5-3 illustrates these changes.

The illustration identifies the transistors as *A*, *B*, and *C*. Each transistor is capable of providing 10 A of sparking electricity. Spark-ON and -OFF time remains the same for each of the square-wave diagrams.

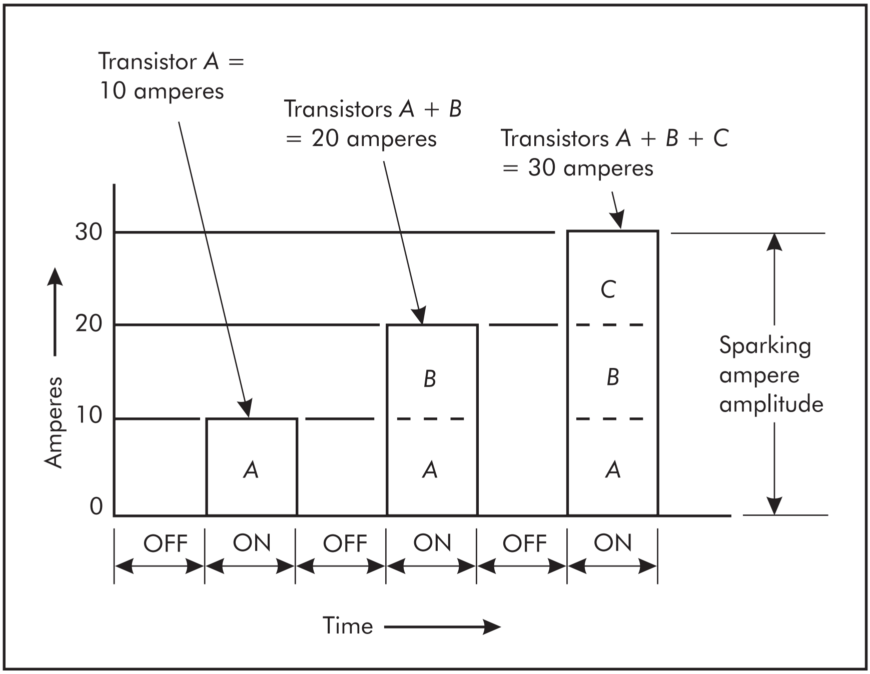


Figure 5-3. Waveform showing increase of sparking amperes.

Since the A transistor remains in the sparking circuit at all times, the height of the square wave for this transistor is shown at 10 A. Closing switch #1 and adding the B transistor increases the height of the square-wave diagram to 20 A. Closing switch #2, as well as #1, adds the C transistor to the circuit and increases the height of the square-wave diagram to 30 A.

In electrical terms, the height of the square wave is referred to as the *amplitude*, or the peak amperes of the square wave. Electrically then, adding transistors, and thereby increasing amperes, increases the sparking power by increasing the amplitude of the square wave.

Sparking power is defined as the rate at which work is done. In electrical circuits, the unit that defines power is watt. The watt is expressed by Equation 5-1:

$$W = E \times I \tag{5-1}$$

where:

W = power in watts
E = voltage
I = amperes

Power in an EDM-sparking circuit increases with an increase of either sparking voltage or amperes. Sparking voltage depends on the ionization point of the dielectric fluid. Ionization voltage during the spark-ON time is fairly constant and, therefore, is not a primary factor in increasing sparking power. Increasing sparking amperes increases sparking power.

Sparking watts determine the electrical energy in each spark. Electrical energy is determined by the amount of time the electrical power is in use. Electrical energy for an EDM spark is expressed by Equation 5-2:

$$W_t = E \times I \times t \tag{5-2}$$

where:

W_t = watt time in microseconds
E = sparking voltage
I = peak sparking amperes
t = spark-ON time in microseconds

Watt time determines the heating capability of each spark. Since sparking voltage is nearly constant, peak sparking amperes and spark-

ON time are the primary factors that determine the heating capability of each spark. As either peak sparking amperes or spark-ON time are increased, the energy and the heating capabilities of each spark are increased.

PEAK AND AVERAGE AMPERES

Spark-machining amperes are visually displayed through the use of an ammeter. Figure 5-4 illustrates an ammeter added to the basic transistor sparking circuit.

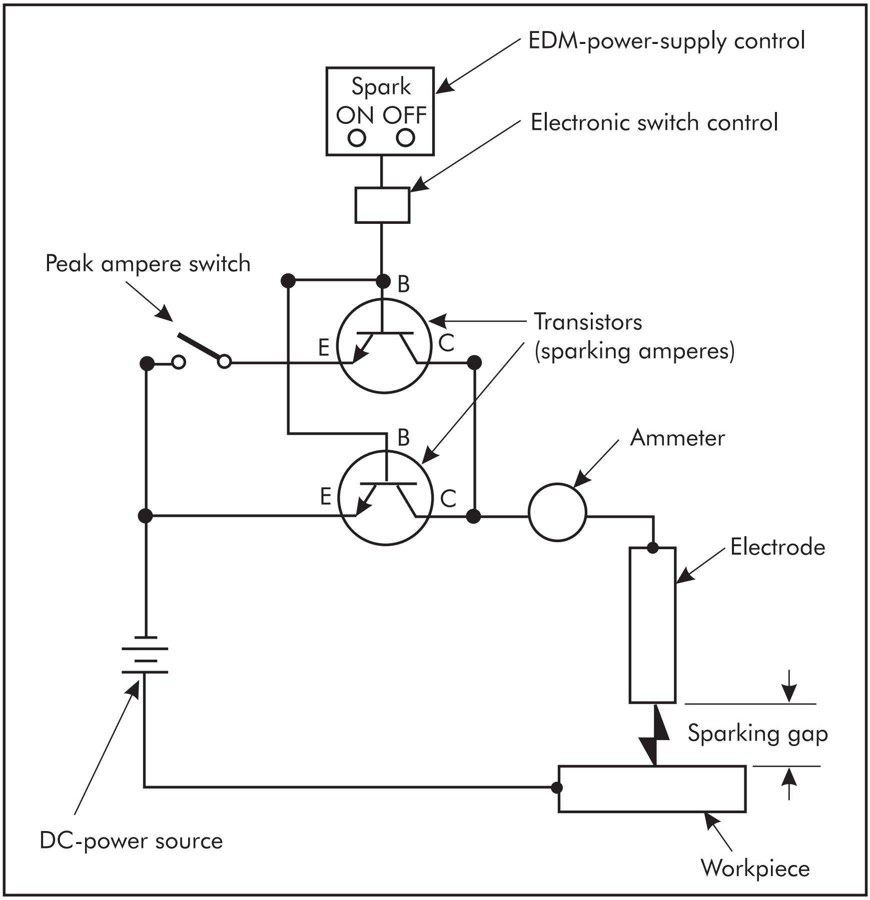


Figure 5-4. Ammeter displays average machining amperes.

All spark-machining amperes must flow through the ammeter. The ammeter indicates only average amperes, rather than the actual peak amplitude of the sparking amperes. This is because sparking amperes do not flow continuously, but in pulses, due to the spark-ON and -OFF time. There are two types of amperes:

1. peak amperes—determined by the amplitude of the amperes as shown by the square-wave diagram; and
2. average amperes—determined by peak amperes, with consideration for the spark-ON and -OFF time.

Figure 5-5 illustrates how spark-ON and -OFF time determine the average-ampere reading displayed by the ammeter. Each spark-ON and -OFF time is shown as five microseconds. Spark amplitude is shown as 10 peak amperes. Without spark-OFF time, electricity would flow continuously and the ammeter would display 10 amperes, which is equal to the peak ampere output shown on the square wave. Sparking amperes do not flow continuously and the ammeter will not display peak

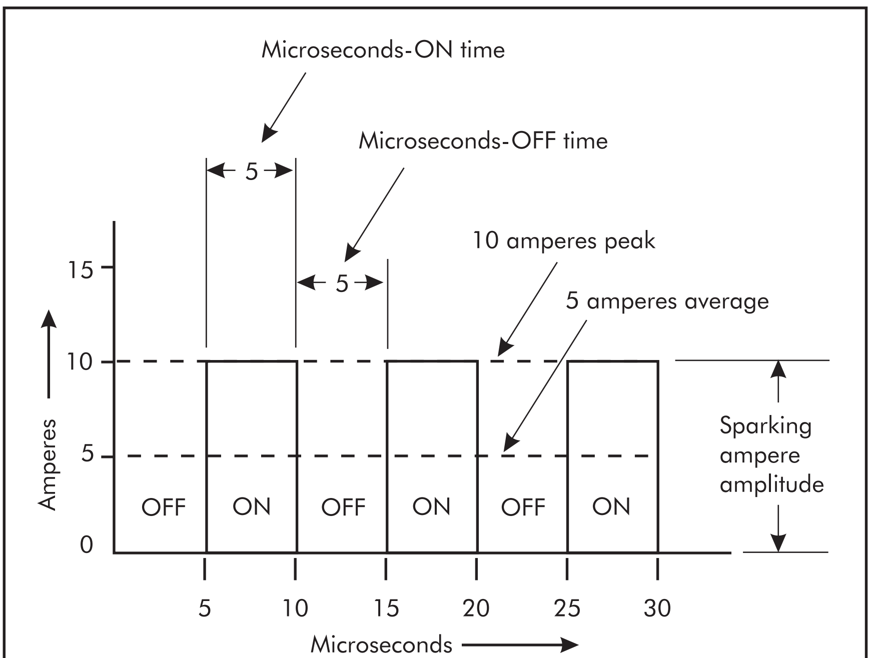


Figure 5-5. Display based on spark-ON/OFF time and peak amperes.

amperes. In this illustration, sparking amperes flow only one-half of the time, since the spark is ON and then OFF for five microseconds each. The ammeter averages the peak sparking amperes and displays five average amperes.

DUTY CYCLE

Rarely are spark-ON and -OFF times equal in actual EDM operations. To determine average machining amperes, calculate the ratio of spark-ON to -OFF time by using Equation 5-3 to find the duty cycle.

$$\text{Duty cycle} = \text{ON}/(\text{ON} + \text{OFF}) \tag{5-3}$$

where:

ON = spark-ON time in microseconds
OFF = spark-OFF time in microseconds

Knowing the spark duty cycle and the peak amperes, average machining amperes may be calculated by Equation 5-4:

$$I_a = I_p \times \text{duty cycle} \tag{5-4}$$

where:

I_a = average amperes
I_p = peak amperes

EDM-power-supply output is rated in amperes. Ampere output indicates the material-removal capability of the unit. Manufacturers do not always rate the ampere output of the EDM-power supply in the same manner. For example, the material-removal capability of an EDM-power supply will be quite different based on a long duty cycle, as compared to a short duty cycle, even though the peak ampere output for both units is the same.

Figure 5-6 illustrates average-ampere output based on a short duty cycle, with a peak output of 100 A. This illustration provides the information required for determining the duty cycle (Equation 5-3) and average ampere output (Equation 5-4):

$$\begin{aligned}\text{Duty cycle} &= \text{ON}/(\text{ON} + \text{OFF})\\ &= 60/(60 + 140)\\ &= 60/200\\ &= 0.3\end{aligned}$$

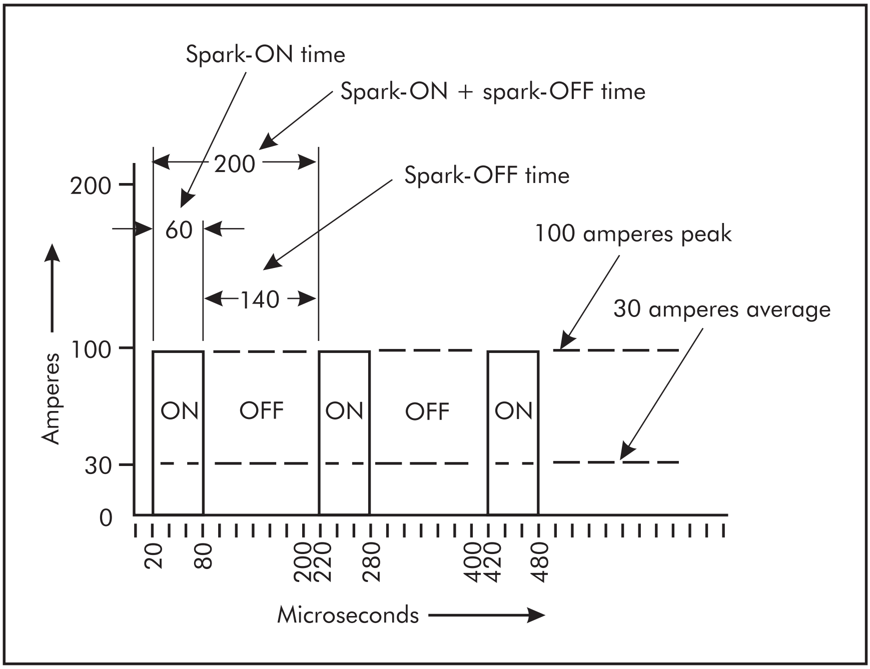


Figure 5-6. Average-ampere output based on short duty cycle.

$$
\begin{aligned}
\text{Average amperes} &= \text{peak amperes} \times \text{duty cycle} \\
&= 100 \times 0.3 \\
&= 30
\end{aligned}
$$

Figure 5-7 illustrates average amperes based on a long duty cycle with a peak output of 100 A.

In Figure 5-7, the spark is ON much longer than it is OFF, and it produces a long duty cycle that increases average amperes. From the square-wave graph, it is possible to calculate duty cycle and average ampere output:

$$
\begin{aligned}
\text{Duty cycle} &= \text{ON/(ON + OFF)} \\
&= 180/(180 + 20) \\
&= 180/200 \\
&= 0.9
\end{aligned}
$$

$$
\begin{aligned}
\text{Average amperes} &= \text{peak amperes} \times \text{duty cycle} \\
&= 100 \times 0.9 \\
&= 90 \text{ A}
\end{aligned}
$$

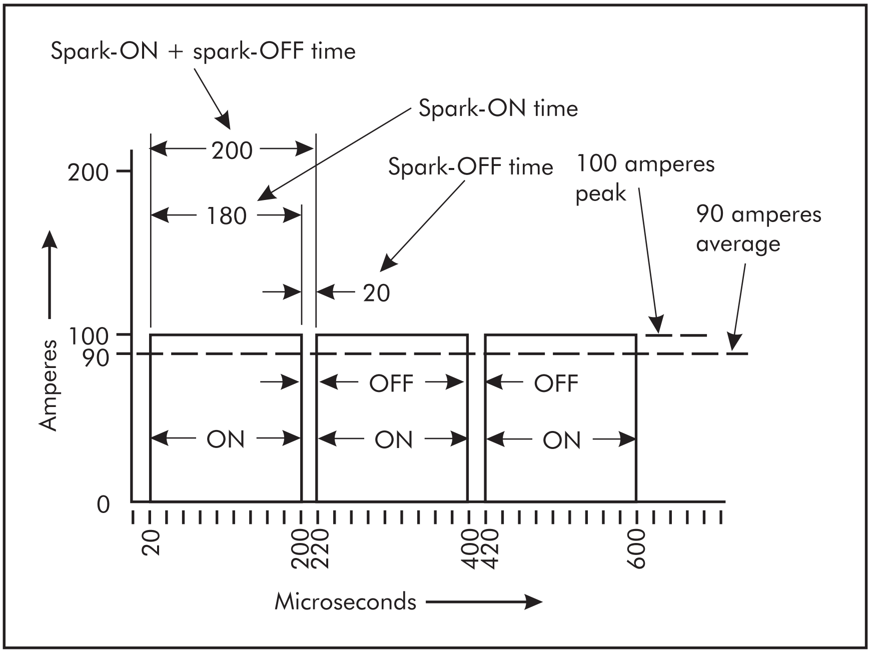


Figure 5-7. Average ampere output based on long duty cycle.

There are times when the average machining amperes and the spark-ON and -OFF times are known. This allows the power supply's peak ampere output requirement to be calculated. Figure 5-8 shows the waveform for this set of conditions. Using the information from this illustration, peak amperes may be calculated as follows:

$$
\begin{aligned}
\text{Duty cycle} &= \text{ON}/(\text{ON} + \text{OFF}) \\
&= 60/(60 + 140) \\
&= 60/200 \\
&= 0.3
\end{aligned}
$$

$$
\begin{aligned}
\text{Peak amperes} &= \text{average amperes/duty cycle} \\
&= 60/0.3 \\
&= 200\ \text{A}
\end{aligned}
$$

EDM manufacturers often express the duty cycle as a percentage. To convert the decimal to a percentage, multiply the decimal number by 100. For example, when a 0.3-duty cycle is multiplied by 100, it becomes a 30%-duty cycle.

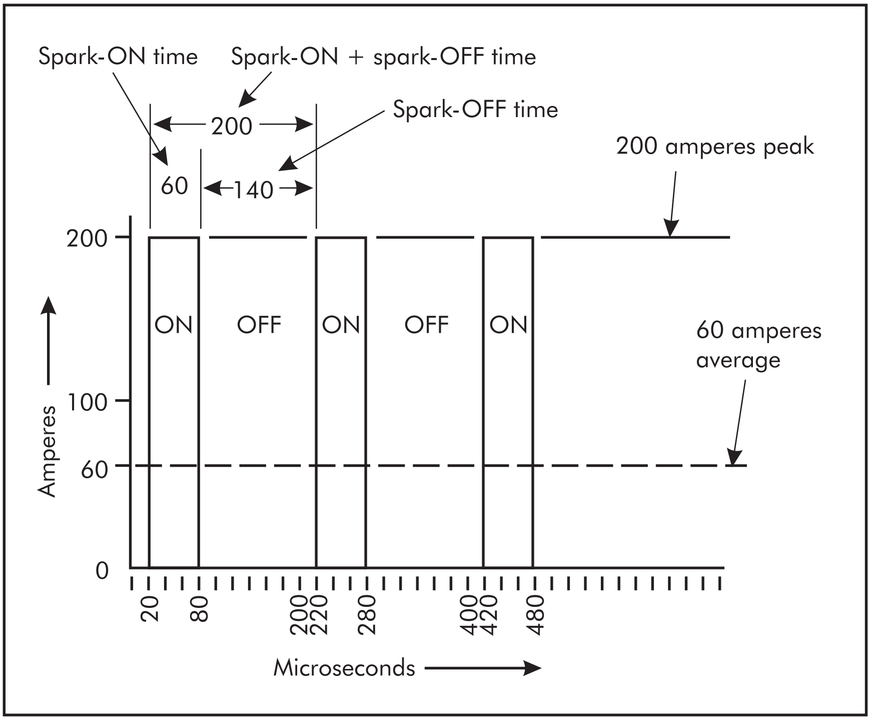


Figure 5-8. Peak amperes based on average amperes and duty cycle.

When an EDM application is duplicated using different EDM machines, it is important to know the spark-machining parameters. Spark-ON time, spark-OFF time, average machining amperes, and peak amperes must be known or calculated to exactly duplicate the sparking power and energy conditions.

RESISTOR-CAPACITOR (R-C) -TYPE EDM-POWER SUPPLY

With an understanding of the electronic switch ON/OFF-EDM-power supply, it is now possible to investigate the resistor-capacitor (R-C)-power supply. Figure 5-9 illustrates the basic R-C-power supply sparking circuit.

Resistor-capacitor (R-C)-power supplies use the same type of DC-power source used for the electronic-switch, ON/OFF-power supply. The primary difference between the units is how the spark-ON/OFF

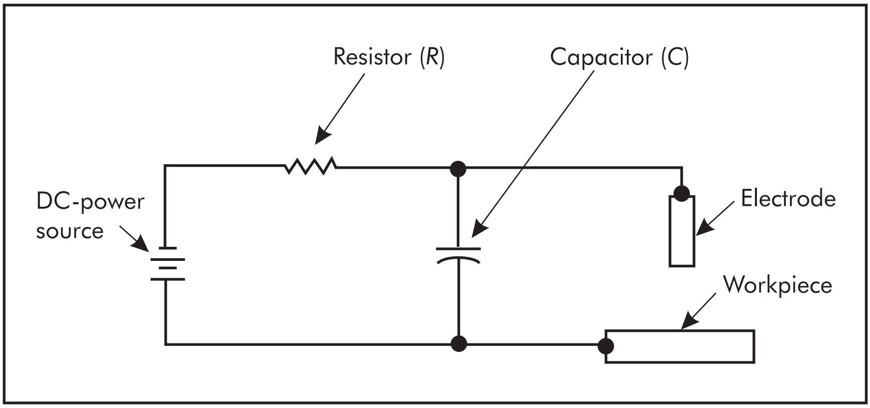


Figure 5-9. Basic resistor-capacitor (R-C)-sparking circuit.

time is determined. The electronic-switch-power supply determines spark-ON and -OFF time through the electronic-switch control. The R-C-power supply determines spark-ON and -OFF time by the values of the resistor and capacitor.

R-C-POWER SUPPLY ELECTRICAL OPERATION

As with the electronic switch ON/OFF-power supply, it is necessary to gain an understanding of the electrical components and terms used to describe the operation of the R-C-power supply. It is not necessary to have an electrical or electronic background to understand how the R-C system operates.

In the R-C circuit, the resistor resists, or holds back, the amount of electricity flowing from the DC-power source to the capacitor. The capacitor stores the electricity that it receives from the resistor. By knowing how the electricity flow is controlled by the resistor and stored by the capacitor, it is possible to establish the ON and OFF time of the EDM sparking. When discussing resistors and capacitors it is necessary to describe the amount of resistance for the resistor and the storage capacity of the capacitor. Resistors are rated in ohms and capacitors are rated in farads.

To gain a better understanding of how the R-C-power supply operates, it is helpful to look at a system that collects and then discharges water from a collection tank. Figure 5-10 illustrates such a system.

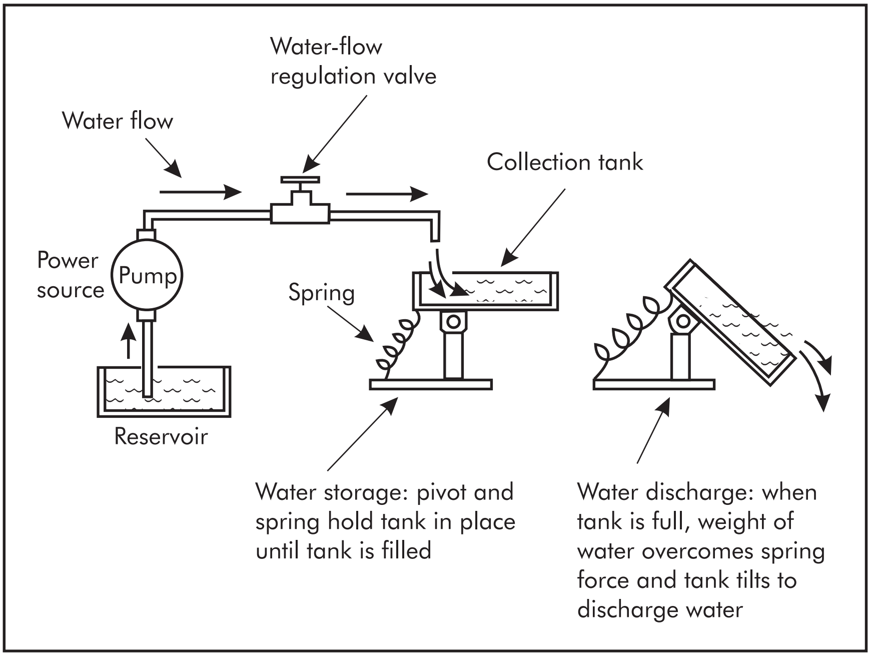


Figure 5-10. Water system to illustrate operation of R-C-power supply.

Figure 5-10 shows how the time required to fill the collection tank to the level where it discharges the water is dependent upon the amount of water flowing through the valve and the storage capacity of the tank. To translate this illustration into electrical circuit terms, the valve can be compared to the resistor, since the valve controls the rate of water flowing from the pump into the collection tank. The collection tank is like the capacitor, since it stores the water until the collection tank is full to the point that water is discharged. Filling the collection tank to the point of discharge is comparable to OFF time and discharging the water is comparable to ON time. Figure 5-11 illustrates an electrical circuit that is equivalent to the water system.

Electricity flows from the DC-power source through the resistor and is then stored in the capacitor. When the capacitor is charged to its electrical capacity, it discharges through the electrode, through the workpiece, and through the sparking gap in the form of a spark. The point of spark discharge depends upon the ionization of the dielectric fluid, which is based on the dielectric strength of the fluid. Spark-OFF

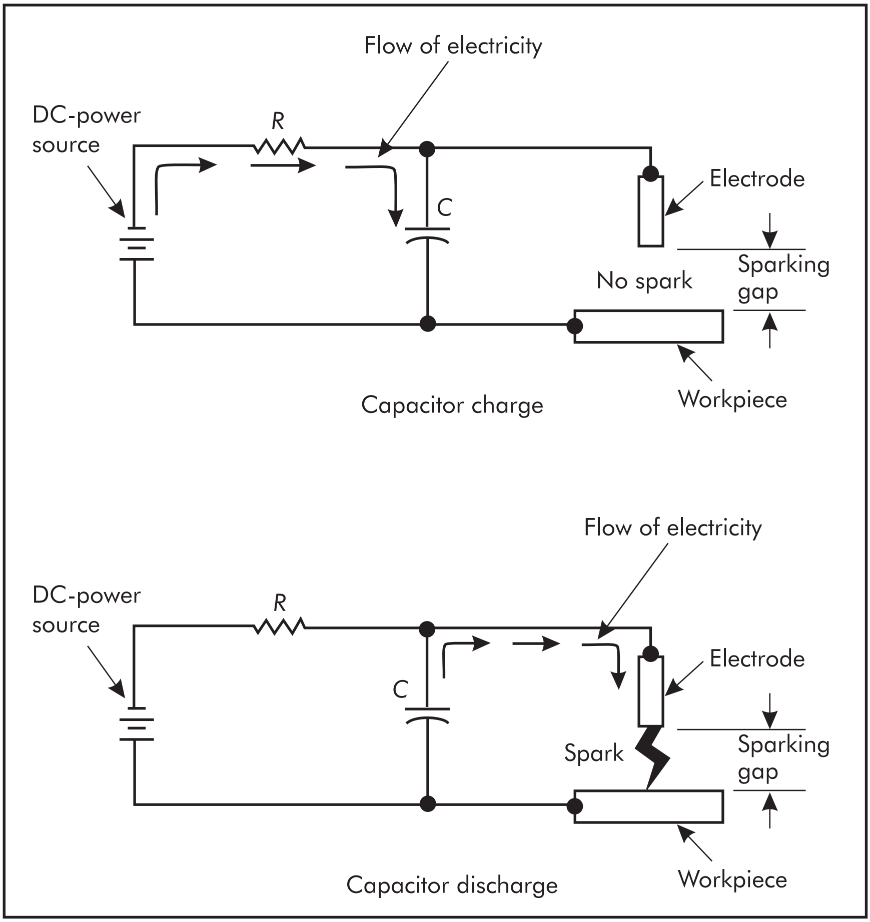


Figure 5-11. R-C, power-supply system for capacitor charge and discharge.

time is the time when the capacitor is being electrically charged. Spark-ON time is when the capacitor is discharged.

Figure 5-11 is not complete from an electrical description standpoint. An electrical circuit is always completed from the source through the circuit components and then back to the source. In the drawing, the electricity's flow path back to the source is unnecessary to the illustration.

Spark-ON/OFF time is determined by Equation 5-5:

$$T = R \times C \qquad (5\text{-}5)$$

where:

T = time (seconds)
R = resistance (ohms)
C = capacitance (farads)

R-C SPARK ON/OFF TIME

Resistance in *ohms* specifies the amount that the flow of electricity to the capacitor is restricted by the resistor. *Capacitance* in farads specifies the electrical storage capability of the capacitor. Spark-ON/OFF timing is varied through the use of different resistor and capacitor values. Figure 5-12 illustrates how these different values can be selected to produce a range of spark-ON/OFF time.

The waveform of the R-C-power supply is quite different than that of the electronic-switch ON/OFF-power supply. For the R-C type, ON time becomes capacitor-discharge time and OFF time becomes capacitor-charge time. Figure 5-13 illustrates the waveform for an R-C-power supply.

In comparing the two types of power supplies, it is only important to know that they both exist. The electronic switch ON/OFF-power

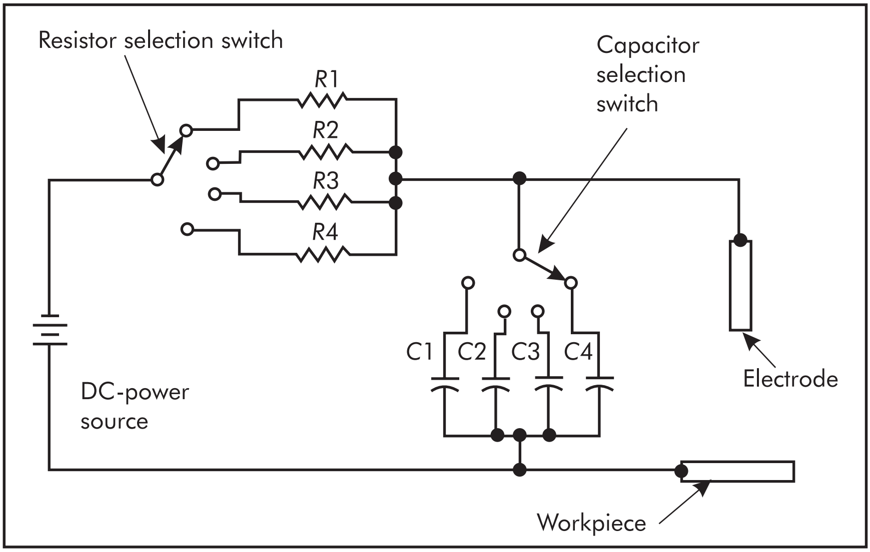


Figure 5-12. Method of changing spark-ON/OFF time.

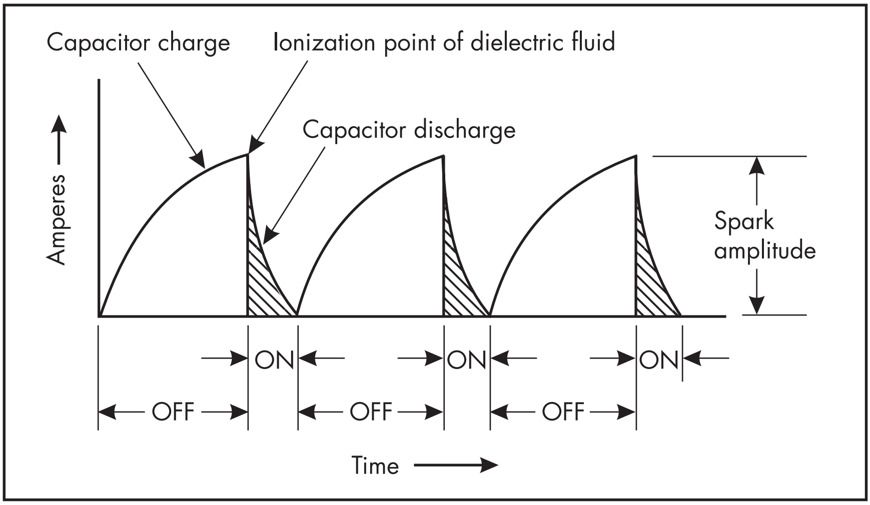


Figure 5-13. R-C power-supply waveform.

supply produces the greatest efficiency for most EDM applications and it is the most commonly used type. R-C-power supplies have an approximate 15A maximum limit for machining. They are also used primarily with metallic electrodes. R-C-power supplies, therefore, work well for applications that require lower ampere-sparking output. Creating fine surfaces or drilling small precision holes are typical applications.

TRANSISTOR POWER SUPPLY MISSING SPARKS

Waveform illustrations, to this point, have indicated that a spark occurs each time the sparking pulse is electrically available. But, since sparking pulses are produced at a frequency of many thousands of pulses per second, not all sparks occur during the time when they are electrically available. Figure 5-14 illustrates what takes place when sparks do not occur for the electronic switch ON/OFF-power supply.

When sparking does not occur in this instance, there is no electricity stored during the spark-ON time. As sparking is re-established, the electricity contained in the next spark is determined by the spark-ON time and by the peak amperes. There is no change in the machined surface or the spark overcut. Machining efficiency reduces as the number of missing sparks increases.

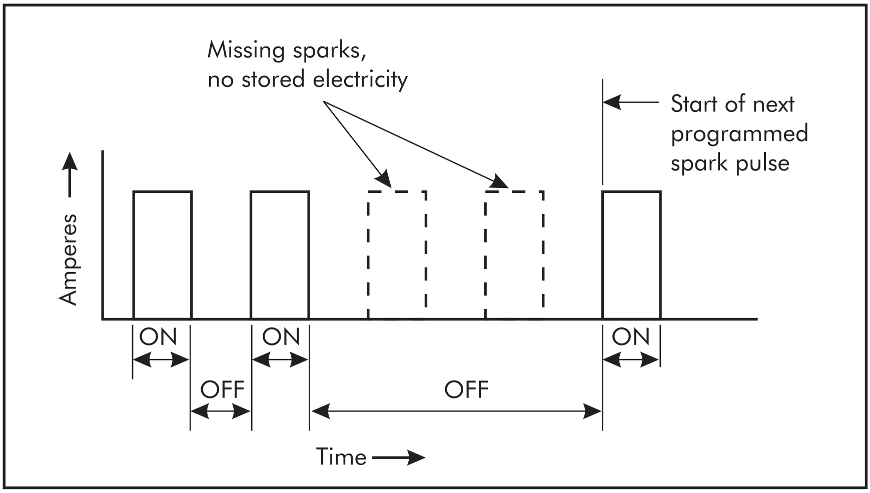


Figure 5-14. Electronic switch ON/OFF-power supply missing sparks.

R-C-POWER SUPPLY MISSING SPARKS

Figure 5-15 illustrates the conditions of the capacitor's electrical charge during missing-spark conditions when using an R-C-type of power supply.

When sparking does not occur using an R-C-power supply, the capacitor remains in a charged condition. As sparking is re-established, the capacitor discharges and starts a normal charge-discharge cycle. Discharged electricity is not increased or decreased during the time of missing sparks. Again, there is no change in the machined surface finish, no change in the spark overcut, and there is a reduction in machining efficiency as the number of missing sparks increases.

Missing sparks are a reality for both types of EDM-power supplies. It is important to note that the amount of electricity contained in the spark following the missing sparks is not increased or decreased. However, this condition causes machining "efficiency" to be detrimentally affected.

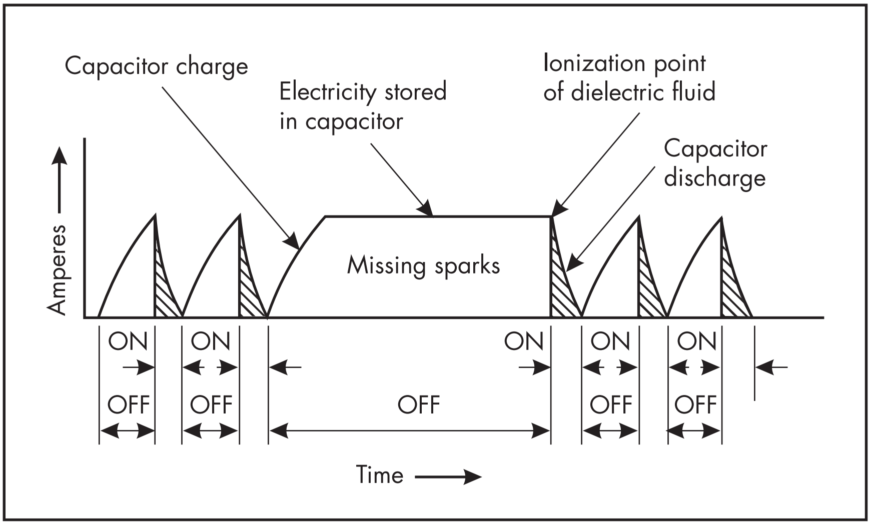


Figure 5-15. R-C-power supply missing sparks.

SUMMARY

Both electronic-switch ON/OFF and R-C-power supplies are used in die-sinker- and wire-cut-machining applications. In general, the R-C-power supply is primarily considered for applications that require a fine surface finish or for the drilling of small, precise micro-holes. The electronic-switch, ON/OFF-power supply has the capability of machining with either graphite or metallic electrodes at higher amperes. This does not mean that the electronic switch ON/OFF-power supply is recommended for all EDM-machining applications. Should there be any question as to the type of EDM-power supply to be used, the particular application should be discussed with the applications people from the EDM manufacturers. In most instances, they will make recommendations and possibly provide a demonstration to confirm them.

EDM Spark Voltage 6

VOLTAGE AND AMPERES

Voltage, in the flow of electricity, is referred to as electrical pressure, force, or electromotive force (EMF). In EDM, voltage is the pressure that makes amperes flow in the form of a spark. Amperes are the spark electricity.

COMPARING WATER AND ELECTRICITY

Voltage and amperes can be illustrated through the use of a water system. Figure 6-1 shows a water reservoir, pump, valve, and hose. This system causes water to flow from the reservoir and out through the hose when the pump is in operation and the valve open. The pump is capable of supplying water to the system at the rate of 10 gal/min (38 L/min) and a pressure of 40 psi (3 kPa). These specifications show that the rate at which the water is supplied represents electrical amperes and that the water pressure is representative of electrical voltage.

Water is contained in the system but it will not flow until the regulating valve is open and until the pump develops enough pressure to force it through the system. To make an electrical comparison, the water flow represents amperes and the water pressure represents the voltage. The valve controls the flow of water to the hose's output. From an electrical standpoint, the valve represents a transistor.

The EDM-sparking system supplies electricity through an electrical circuit that is quite similar to the water system. Figure 6-2 illustrates this basic electrical circuit.

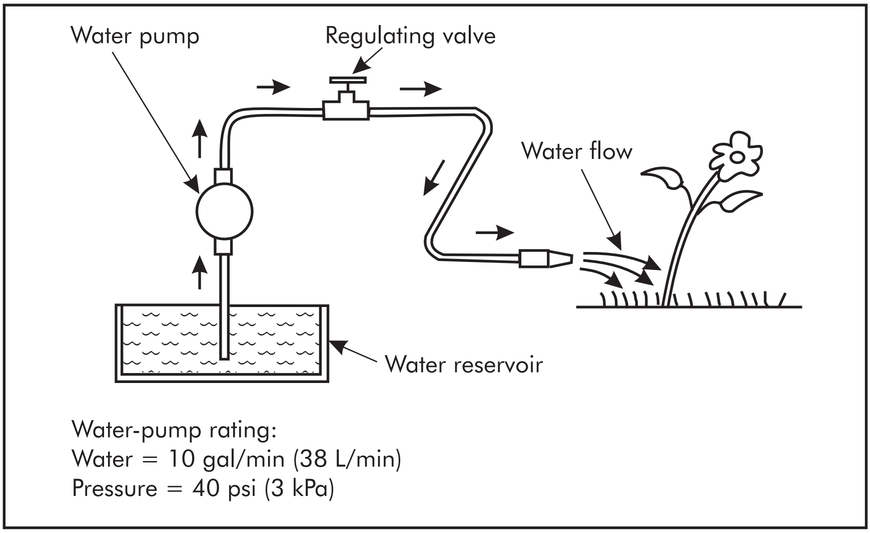


Figure 6-1. Water flow by means of pump pressure.

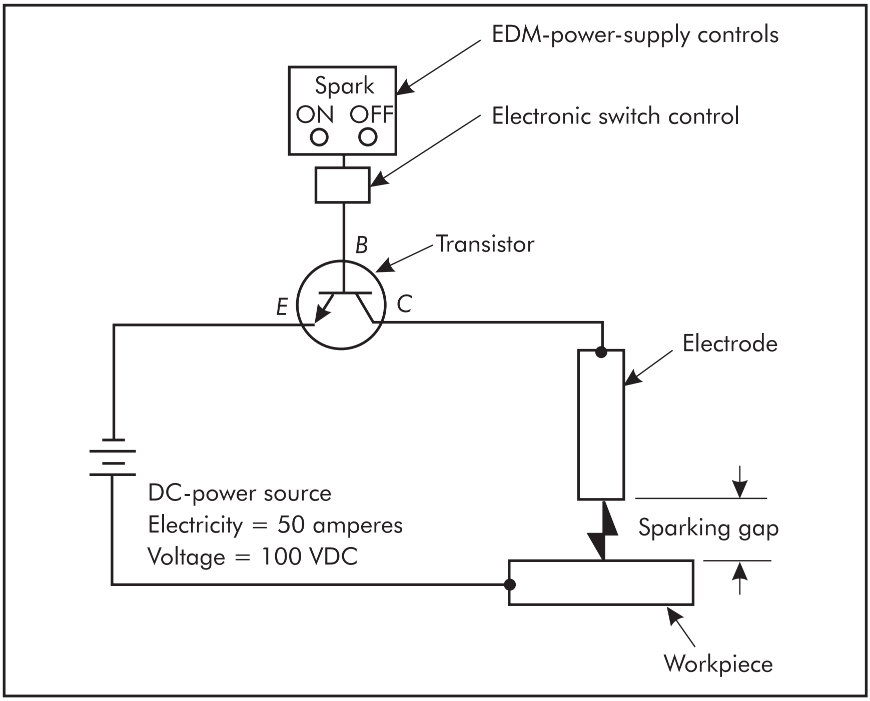


Figure 6-2. Basic electrical circuit for sparking.

IONIZATION

Dielectric fluid ionization, voltage, and time affect the flow of electricity and sparking.

IONIZATION ALLOWS ELECTRICAL FLOW

Ionization is the process by which an electron is removed from an atom, molecule, or ion. This process is of basic importance to electrical conduction in liquids. In the simplest case, ionization is like a transition between an initial state, consisting of a neutral atom, and a final state, consisting of a positive ion and a free electron.

The DC-power source provides electrical pressure as voltage, and sparking electricity as amperes. Figure 6-2 specifies voltage and amperage at 100 V of direct current (100 VDC) and 50 A. The actual voltage available for EDM sparking is specified by the manufacturer for each machine to suit the needs of the EDM-power-supply design. Voltage in an EDM-sparking circuit is measured across the sparking gap between the electrode and the workpiece, where the spark occurs during the spark-ON time. The transistor allows electricity to be available at the sparking gap during the ON time, but the spark will not occur until the dielectric fluid ionizes to allow the passage of the electricity. There are two different conditions that can then occur:

1. the dielectric fluid *will not* ionize during the transistor-ON time when the voltage is applied across the sparking gap; or
2. the dielectric fluid *will* ionize during the transistor-ON time when the voltage is applied across the sparking gap.

Figure 6-3 illustrates these two conditions.

When the dielectric fluid does not ionize, the voltage is applied to the sparking gap. Yet, there is no flow of electricity between the electrode and the workpiece through the dielectric fluid. Here, the square-waveform shape rises from zero to the 100-VDC point. It remains there until the OFF time makes the voltage drop to zero. This happens when the electrode-to-workpiece spacing is larger than the dimension at which a spark occurs. This is known as the *open-circuit voltage*. Open-circuit voltage for most EDM-power supplies is approximately 100 VDC. The manufacturer specifies exact open-circuit voltage for any particular

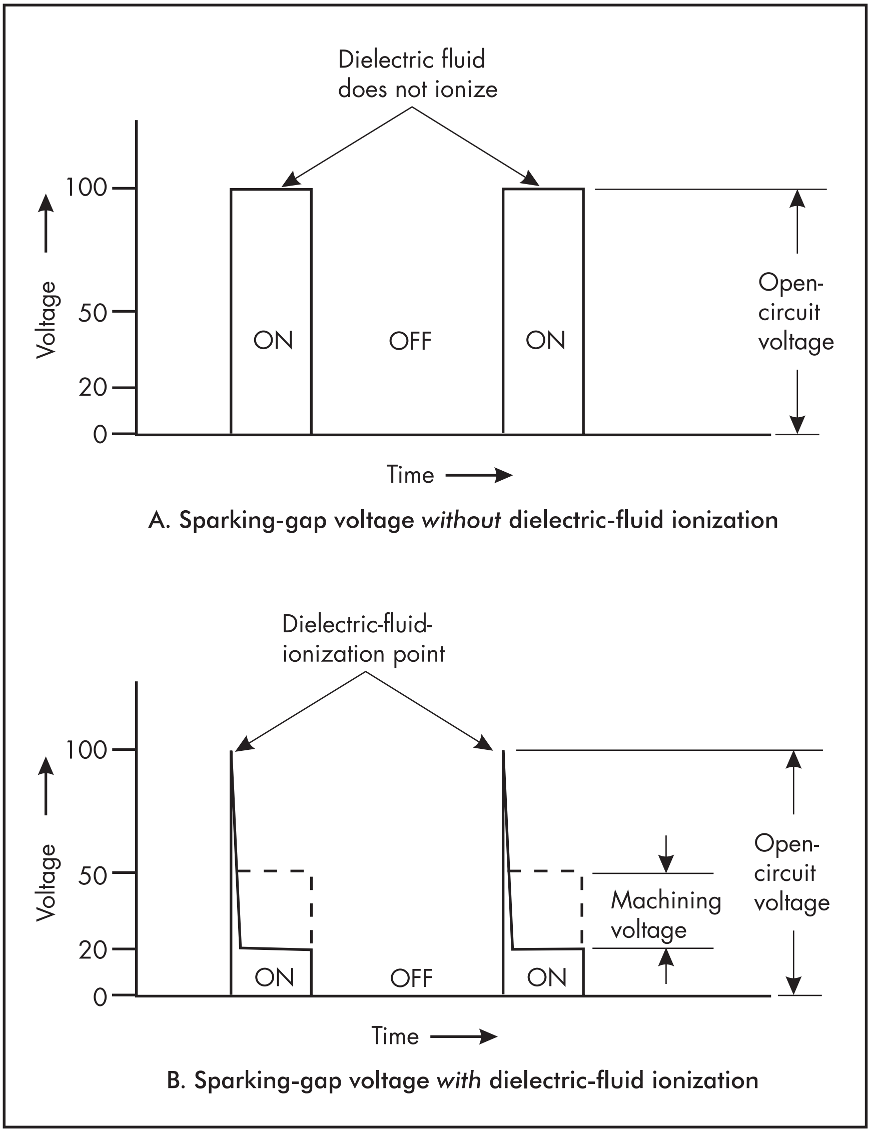


Figure 6-3. Sparking-gap voltage without (A) and with (B) ionization.

power supply to suit the electronic design requirements. It is important to note that open-circuit voltage means that there is the possibility of an electrical shock. The manufacturer's instructions and the use of protective guarding need to be observed to prevent electrical shock.

When dielectric-fluid ionization does occur during the transistor-ON time, electricity in the form of a spark flows through the dielectric fluid. This dielectric-fluid ionization normally occurs at the beginning of the transistor-ON time. As the electricity flows through the fluid, the voltage between the electrode and workpiece is reduced almost instantaneously from the open-circuit voltage of 100 VDC to between 20 and 50 VDC, a voltage range where sparking occurs. This voltage is known as the *machining voltage*. The dielectric strength and electrical characteristics of the dielectric fluid during ionization establish the actual value of this reduced voltage. A note: even though the voltage is reduced considerably, care still should be exercised to prevent electrical shock.

DELAY OF IONIZATION SLOWS SPARKING

Dielectric-fluid ionization does not always occur at the beginning of the ON-time period. It is possible for it to occur at any time during the transistor-ON time period. Figure 6-4 illustrates typical waveforms for normal and delayed dielectric-fluid ionization, after open-circuit voltage is applied to the sparking gap.

NORMAL SPARK VOLTAGE AND AMPERES

Both voltage and amperes are important to analyze what takes place when a spark occurs in the sparking gap. First, voltage is applied between the electrode and workpiece during the transistor-ON time. Then, when ionization of the dielectric fluid takes place, amperes flow through the sparking gap in the form of a spark. Figure 6-5 illustrates the voltage and ampere waveforms during a normal spark.

During this process, the transistor switch closes for the ON-time period; the DC-power source, open-circuit voltage is applied to the electrode and to the workpiece across the sparking gap; and dielectric-fluid ionization takes place. At the point of ionization, the sparking-gap voltage is reduced to machining voltage and electricity flows between the electrode and workpiece in the form of a spark. The flow of amperes is instantaneous with the ionization point and it continues for the complete transistor-ON time. In the illustration, the amperes are shown as 50 A. Actual amperes are determined by means

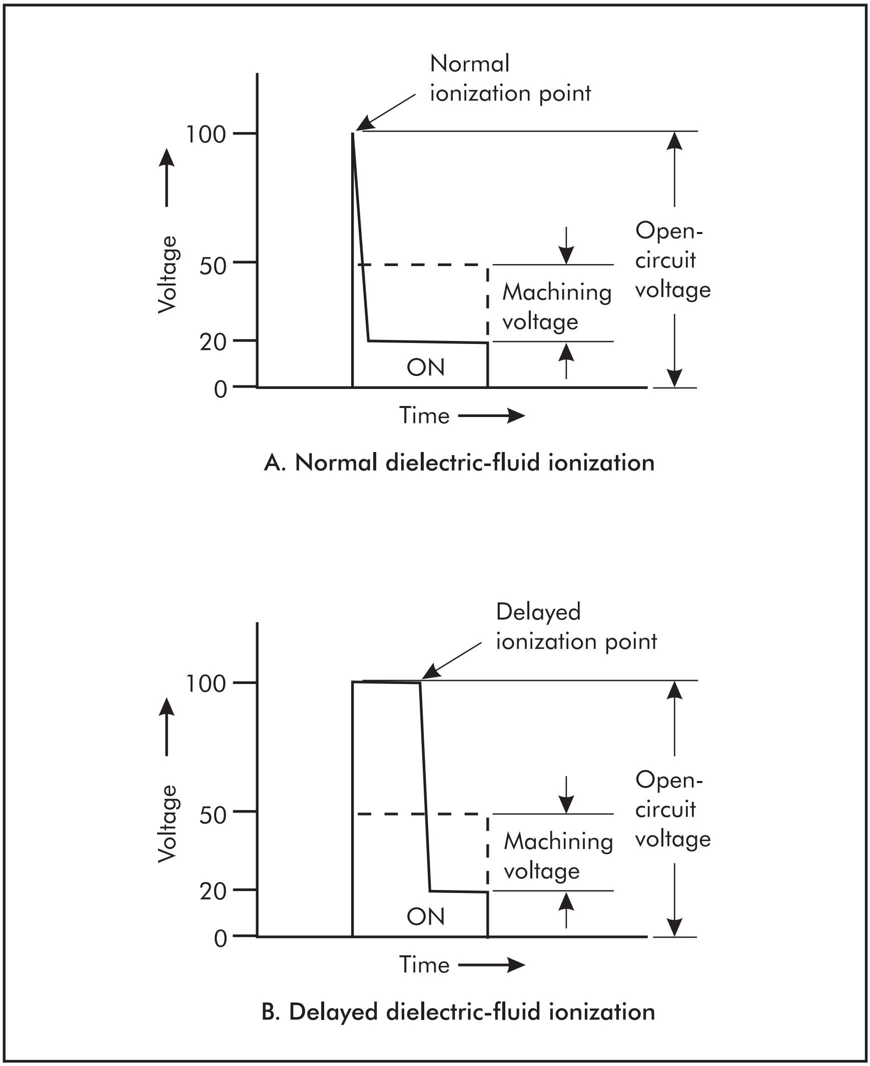


Figure 6-4. Machining voltage due to ionization. Normal is seen in (A) and delayed in (B).

of power-supply settings that are obtained from manufacturer/operational data for a particular machining application.

Since dielectric-fluid ionization takes place at any time during the transistor-ON time period, ampere-ON time varies, based on the ionization point of the dielectric fluid. Figure 6-6 illustrates this point.

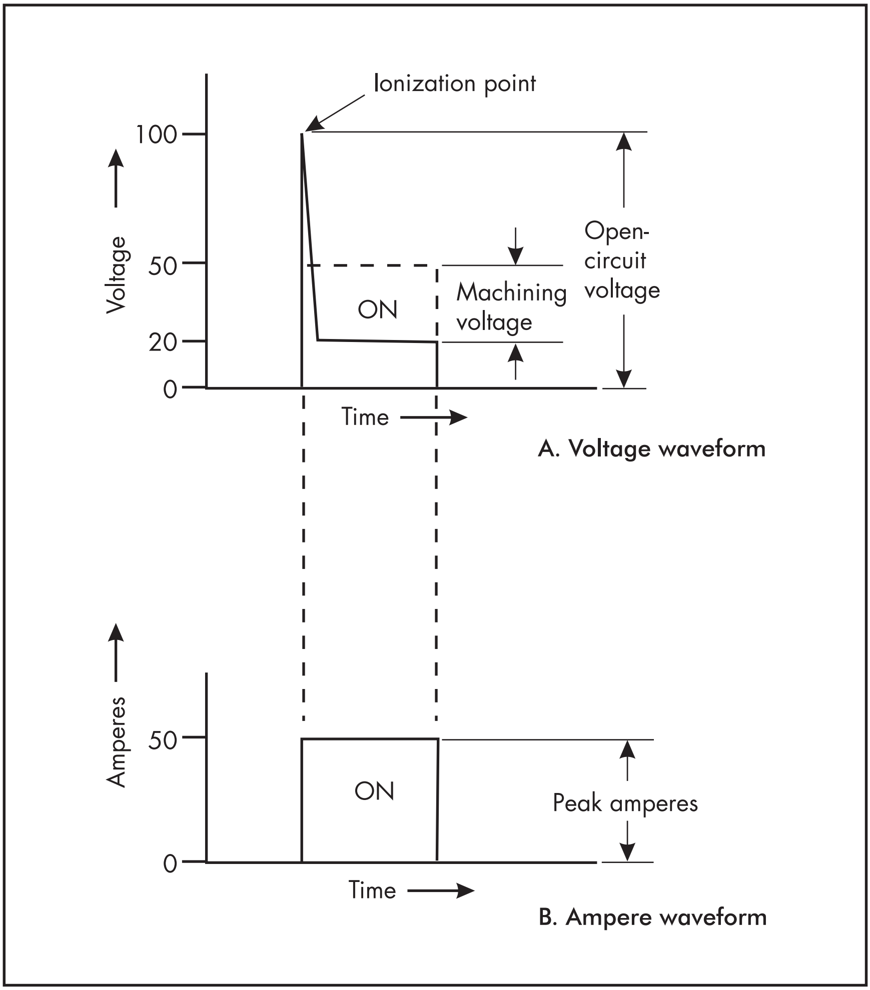


Figure 6-5. Normal spark voltage (A) and ampere waveforms (B).

DELAYED IONIZATION AND AMPERE REDUCTION

A delay in the dielectric-fluid-ionization point during the ON-time period causes the spark-ON time to be reduced. This reduction of spark-ON time reduces the amount of material removed by the spark. There are, however, EDM-power supplies that always produce sparks with equal ON time. Figure 6-7 shows equal ON-time sparks, based on the dielectric-fluid-ionization point.

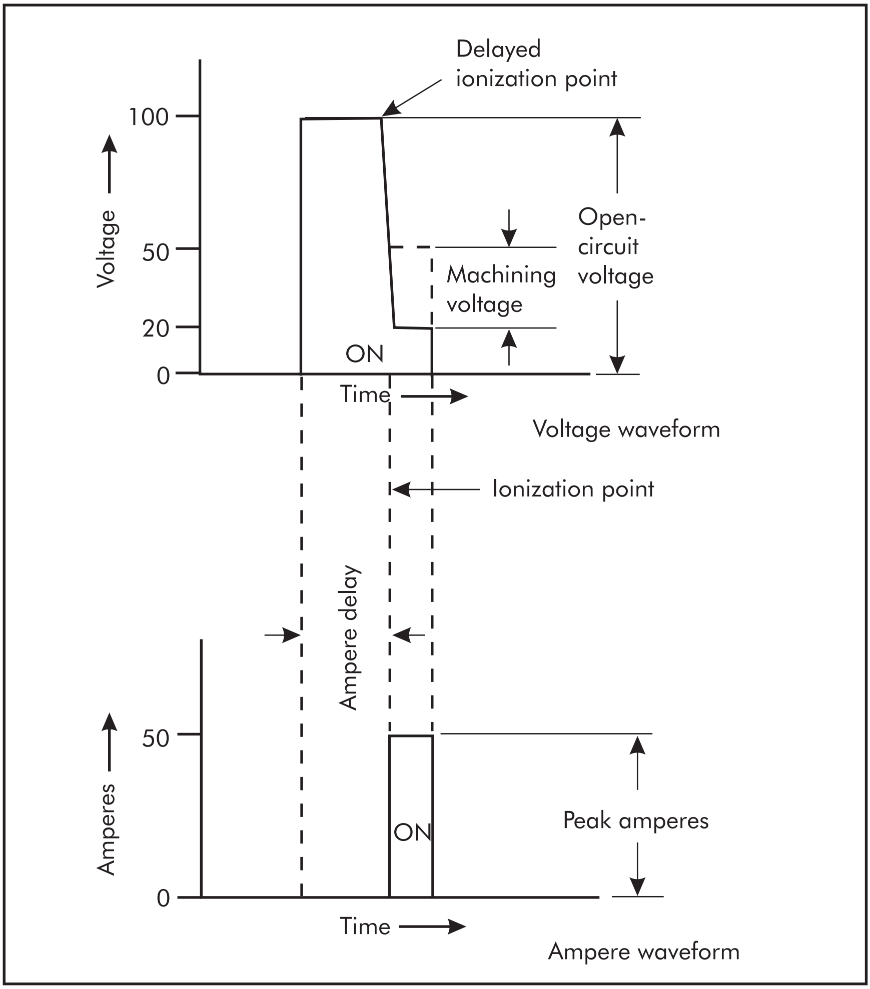


Figure 6-6. Ampere ON-time delay, due to ionization.

EQUAL ON-TIME FOR ALL SPARKS

Equal ON-time sparking is based on starting the spark-ON time at the point of dielectric-fluid ionization. Open-circuit voltage is applied here to the sparking gap. At some point, ionization takes place and ON time commences and stays on for the time set at the power-supply control. Sparking amperes flow only during the time of ionization until

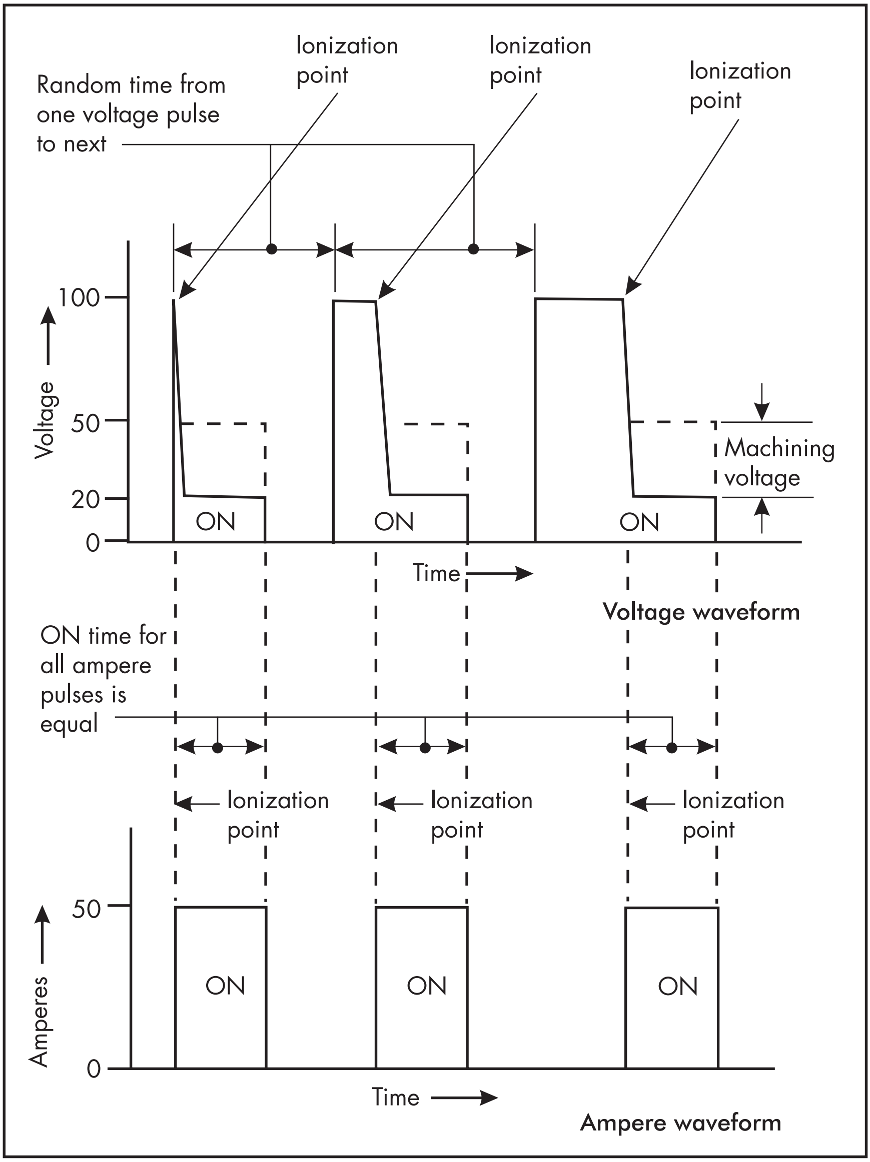


Figure 6-7. Equal spark-ON time based on ionization point.

the OFF time begins. Each spark here is always equal. Equal spark-ON time ensures equal material removal for each spark. It also allows for consistency in the machined surface.

Equal sparking amperes for each spark have the benefit of producing a uniform machined surface finish. Timing of the point of ionization determines the starting point for each ampere-ON time. Total time from the beginning of one spark-ON time to the next is random, based on the fluid ionization point. It is possible for the ionization point to extend to the point where few sparks occur. Should this condition exist, the use of the more normal fixed-ON/OFF time may produce more efficient machining conditions. When set for the same ON and OFF times and amperes, the surface produced by the equal spark-ON-time machine is more uniform than the one created by the variable ampere-ON-time machine. The reason for this difference is that the variable ampere machine's surface is formed by sparks having the same material-removal rate as those for the equal ON time. Furthermore, the sparks will have a reduced material removal rate.

GAP-INITIATION VOLTAGE

Power-supply open-circuit voltage is normally enough to efficiently ionize the dielectric fluid. There are times when machining instability causes the electrode-to-workpiece distance to vary. As a result, sparks will not occur. In an effort to increase the possibility of sparking under these conditions, EDM-electronics designers sometimes use a very short-duration, high-voltage pulse that is superimposed on the leading edge of the ON-time pulse. Figure 6-8 illustrates this concept.

The dielectric strength of the dielectric fluid determines the dimension of ionization when voltage is applied. This short-duration pulse applies a voltage that is considerably higher than the normal open-circuit voltage. Due to higher voltage, ionization takes place here at a greater distance. In addition, this causes the sparking efficiency to be increased.

Even when using the initiation pulse, there is no guarantee that the number of sparks will increase sufficiently to create an increase in machining efficiency.

There are three sparking conditions that are possible when applying a short-duration, high-voltage pulse for increasing sparking efficiency. These conditions are:

1. The process of the initiation pulse causes fluid ionization at the beginning of the spark-ON-time period. The spark-ampere waveform is then equal to the full ON-time period.

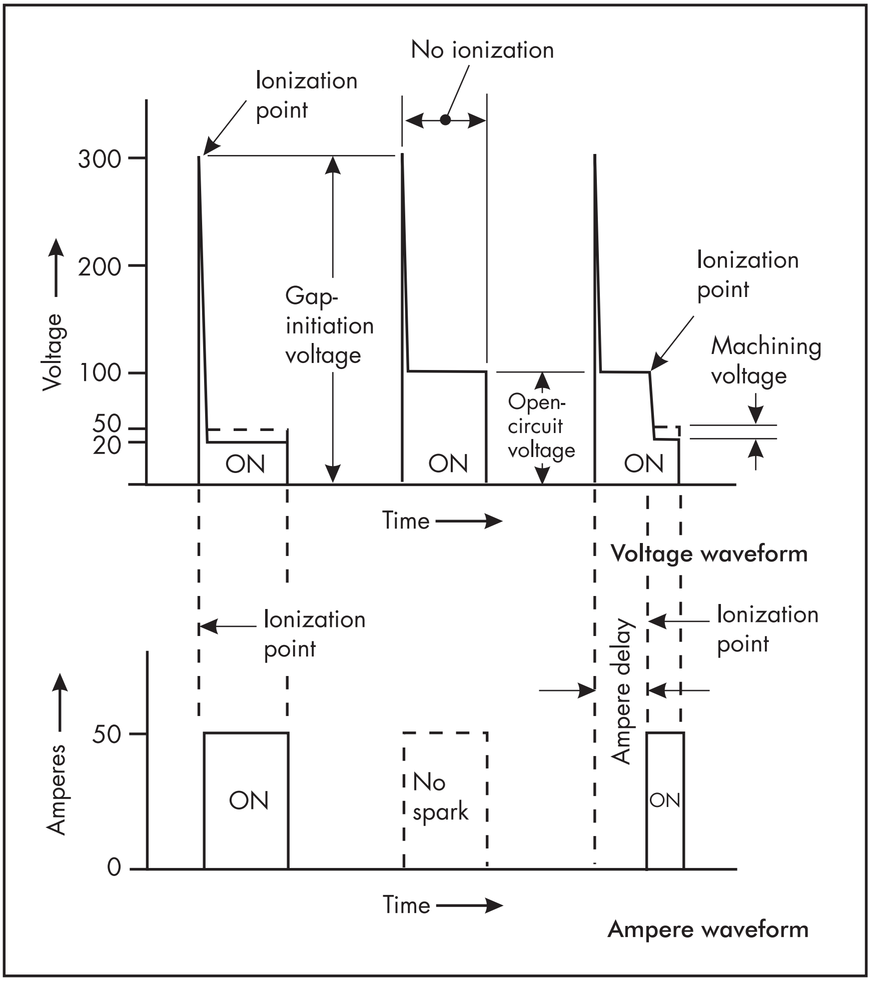


Figure 6-8. Short-duration, gap-initiation voltage pulse.

2. An instance when neither the initiation pulse nor the normal open-circuit voltage cause ionization of the fluid and no spark occurs.
3. The case where ionization does not take place during the initiation pulse, but does take place at some time during the application of the normal open-circuit voltage. In this instance, a spark occurs, but it is not on for the full-ON time.

Application of the short-duration, high-voltage pulse can be beneficial under unstable machining conditions. Depending on the cause of

these conditions, initiation voltage may not beneficially increase sparking efficiency. In addition, under stable machining conditions, the use of the initiation pulse will not increase sparking efficiency.

It may not be obvious that an EDM machine includes some form of short-duration, high-voltage pulsing. This is because this type of pulse is of such short duration that it may not register on the open-circuit-voltage display. Should a machine include this feature, the manufacturer directions for guarding should always be observed to prevent the possibility of electrical shock.

VOLTAGE AND AMMETER

Voltage is monitored by the voltmeter and amperes are monitored by the ammeter. When a voltmeter and ammeter are included as part of the EDM system, they are usually part of the power-supply controls. In computer-controlled machines, voltage and amperes may be displayed on the video monitor. Figure 6-9 shows how the voltmeter and ammeter are connected to the EDM-sparking circuit.

The ammeter is connected so that all sparking amperes flow through it. The voltmeter is connected so that electricity flows parallel through it and the electrode-to-workpiece sparking gap. When the transistor turns the DC-power-source output ON and OFF *without* sparking amperes flowing through the sparking gap, the voltmeter displays the open-circuit voltage. When the transistor turns the DC-power-source output ON and OFF *with* sparking amperes flowing through the sparking gap, the voltmeter displays the machining voltage.

The voltmeter serves as a monitor for displaying the stability of the machining operation. For highest efficiency, the voltmeter needle should only move occasionally. Should the needle move continuously over a wide range, the power-supply-control settings should be reviewed and then possibly reset to stabilize the machining system.

A voltmeter may not be included on all EDM-power supplies. The electronic-circuit designer determines the value of the voltmeter. The designer also determines if the voltmeter should be included as part of the machine controls.

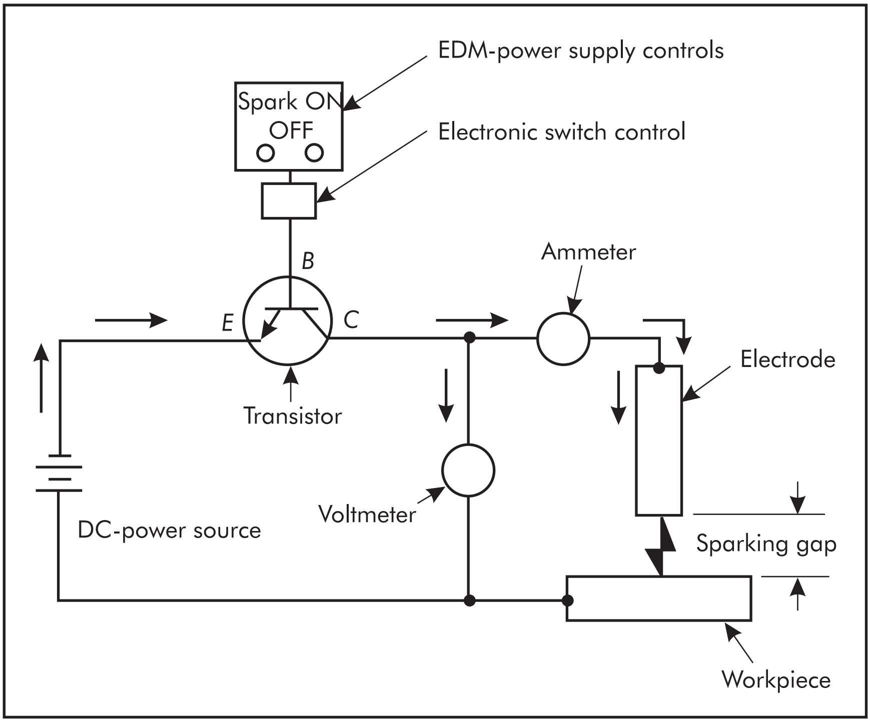


Figure 6-9. Voltmeter and ammeter for monitoring spark electricity.

SUMMARY

In general, voltage and ampere considerations are the same for both the electronic-switch- and R-C-types of EDM-power supplies. Waveforms for the R-C type of power supply are more complex and difficult to describe. Only waveforms for the electronic-switch type of unit have been included since they illustrate how amperes flow in the sparking circuit through the force of voltage.

7

Electrode Servo Systems

This chapter discusses the die-sinker- and hydraulic-servo systems.

DIE-SINKER-SERVO SYSTEM

EDM machines require an automatic system for proper spacing of an electrode from the workpiece. This maintains efficient sparking. Such a system must be versatile enough to work with electrodes as small as .0010 in. (0.025 mm) in diameter, to very large electrodes that weigh hundreds of pounds. This automatic operation is accomplished by the EDM-servo system.

Requirements for an EDM-servo system are:

- the electrode must not touch the workpiece, and
- the electrode must advance toward and retract from the workpiece to maintain the voltage between the electrode and workpiece.

The electrode advance-and-retract system is part of the power supply's electronic control. Die-sinking machines use either an electric motor or a hydraulic unit to drive the machine's servo-head assembly. The system used primarily depends on the size and weight of the electrodes. Large machines using heavy electrodes normally use the hy-draulic servo and those that use smaller electrodes generally use the electric-motor-servo drive. However, either drive may be used for large or small electrode applications. This is because design engineers have systems available that can handle large, heavy electrodes or very small electrodes that require precise control for maintaining the sparking gap. Whichever system is used, the machine should be able to machine efficiently within a range of electrode sizes that represents the work to be accomplished.

SPARKING VOLTAGE

EDM-servo systems make use of the electrical characteristics of the dielectric fluid for their operation. The dielectric fluid acts as an electrical insulator until the open-circuit voltage and spacing between the electrode and workpiece reach the ionization point of the dielectric fluid. The dielectric fluid then changes from an insulator into an electrical conductor, causing the voltage between the electrode and workpiece to drop from the open circuit to sparking voltage. This normally occurs in a range of 20–50 VDC. Figure 7-1 illustrates the difference between open-circuit-sparking voltage.

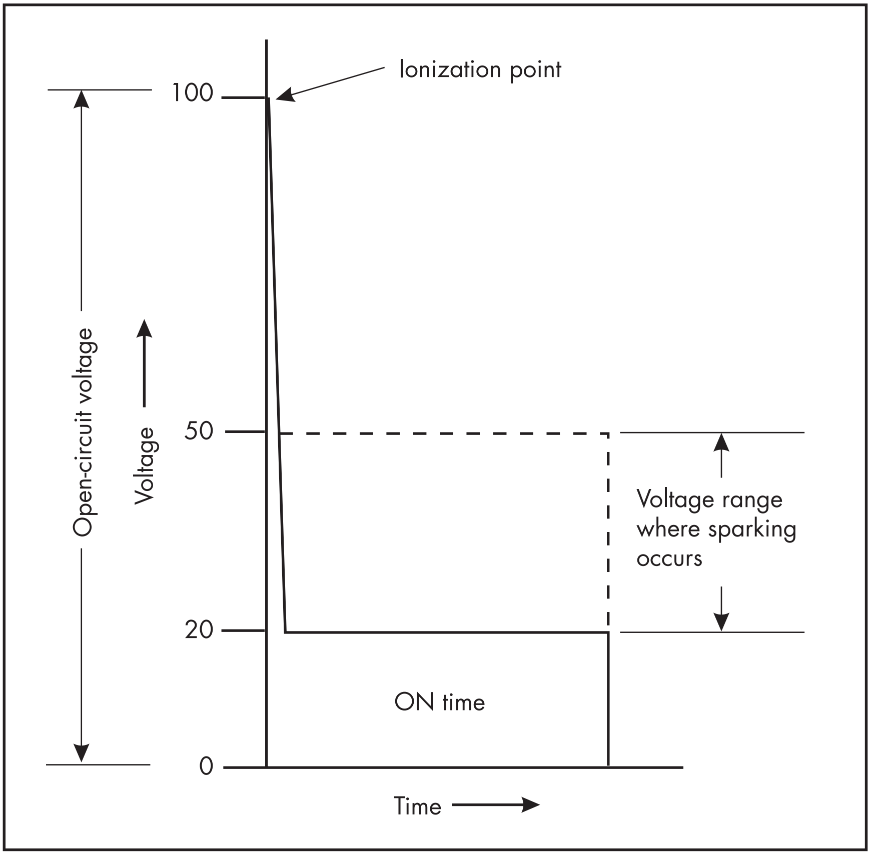


Figure 7-1. Voltage range where sparking occurs.

Once sparking occurs, it will continue within a fairly wide voltage range. The servo-reference voltage should be set at a point in this range that allows for the most stable machining conditions.

SERVO-REFERENCE VOLTAGE

Since the machining-voltage range is constant for a particular dielectric fluid, a voltage in this range is selected as a reference for controlling the servo system. This reference voltage is compared to the actual machining voltage measured between the electrode and workpiece. The difference between the reference voltage and the actual electrode-to-workpiece machining voltage is that the difference in the voltages is used to command the electrode-servo system to advance, hold position, or retract from the workpiece. Figure 7-2 illustrates how servo-reference voltage is selected within the machining voltage range.

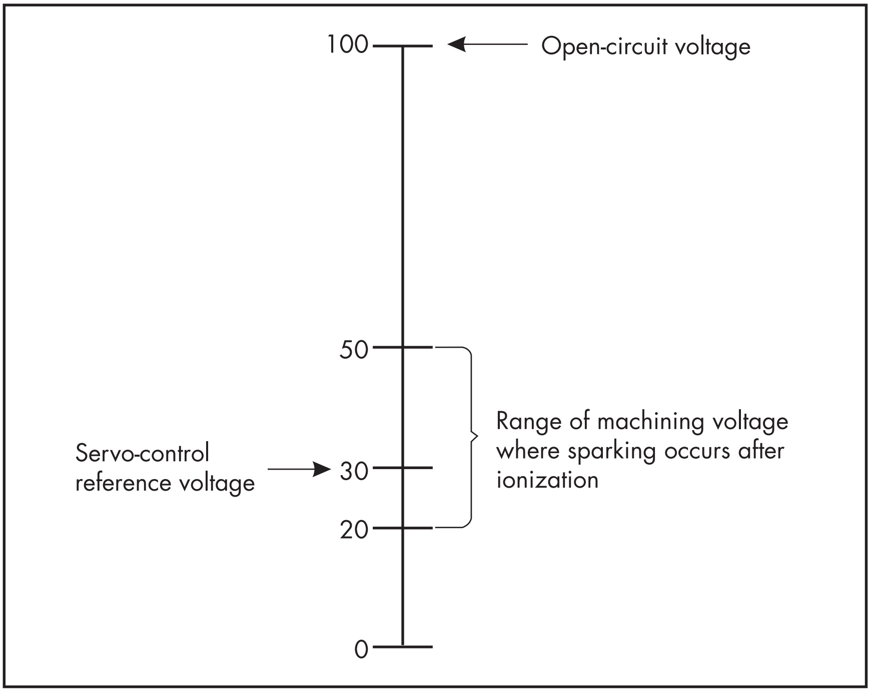


Figure 7-2. Servo-reference voltage within the machining voltage range.

SERVO OPERATION BASED ON MACHINING AND REFERENCE VOLTAGES

The machining voltage range is 20–50 VDC. Here, 30 VDC is selected as the reference voltage for the servo control. The servo control causes the servo-drive system to advance in operation, to hold, or to retract the electrode. This keeps the electrode-to-workpiece machining voltage equal to the 30-VDC-reference voltage. Should the machining voltage be greater than 30 VDC, the servo system will advance the electrode closer to the workpiece until the machining voltage is once again equal to 30 VDC. At this point, the servo system will stop advancing the electrode and hold it in position until there is again a difference between the machining and reference voltages.

During the machining operation, as sparking is taking place with the electrode-to-workpiece machining voltage and the reference voltage both being equal to 30 VDC, the servo system holds the electrode at that point. As sparking continues, material is removed from the electrode and workpiece. Removal of the material causes the distance between the electrode and workpiece to increase. This increase in distance causes the electrode-to-workpiece voltage to become greater than the 30-VDC-reference voltage. The servo system then advances the electrode to decrease the electrode-to-workpiece spacing and again have the machining voltage equal to the 30-VDC-reference voltage.

When the electrode advances toward the workpiece to where the machining voltage is less than the 30-VDC-reference voltage, the servo system will retract the electrode from the workpiece until open-circuit voltage is detected. Once detected, the servo system will again advance the electrode until sparking commences and the electrode-to-workpiece machining voltage is equal to the 30-VDC-reference voltage.

Actual servo control, using a specific voltage such as 30 VDC, is not practical since the servo system would constantly be moving to attempt to keep the machining voltage equal to the reference voltage. EDM-servo-system designers let the electrode-to-workpiece machining voltage vary over a fairly narrow range, yet still be acceptable to provide stable machining conditions. Figure 7-3 illustrates a servo-control system using a 30-VDC-reference voltage that allows an electrode-to-workpiece machining-voltage range of 28–32 VDC. This occurs before the servo system reacts to cause movement of the electrode. Allowing this machining voltage variance, before action is taken by the servo

system, produces stable servo operation that would be impossible if an exact reference voltage were to be compared to the actual machining voltage.

The action of the servo system is incremental. This is because the electrode advances during sparking until the electrode-to-workpiece machining voltage is increased to 32 VDC. The electrode then advances until the electrode-to-workpiece machining voltage is again 30 VDC. Servo-system action advances, holds, and advances again as the electrode-to-workpiece voltage increases and then adjusts to be equal to the reference voltage.

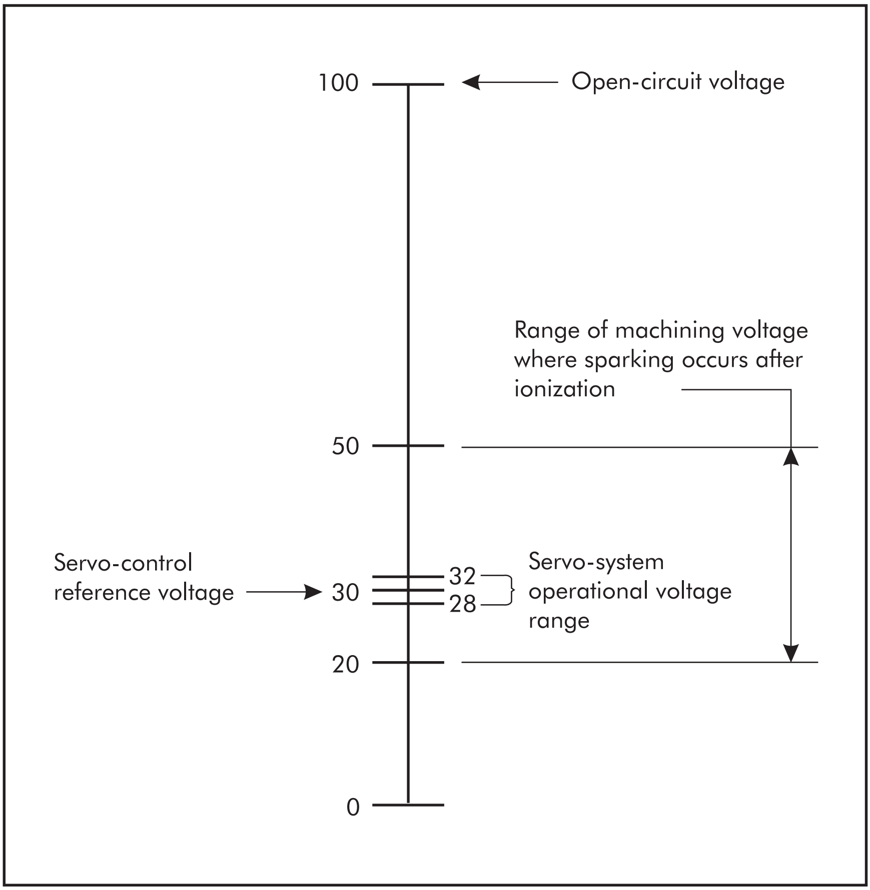


Figure 7-3. Servo operational voltage range.

There are times when the electrode-to-workpiece machining voltage is less than the lower limit allowed for servo-system operation. Should the electrode-to-workpiece machining voltage fall to 28 VDC, the servo system will retract the electrode until the machining voltage is again equal to the 30-VDC-reference voltage. It is also possible to have a servo system that retracts the electrode at a lower servo-voltage limit and then continues the retraction until the power supply's open-circuit voltage is detected. This offers the benefit of opening up the electrode-to-workpiece spacing so that machining debris will have a larger opening to exit the sparking area, ensuring a clear sparking area.

SERVO-SYSTEM DESIGN REQUIREMENTS

Design requirements for an EDM-servo system can be summarized by the following three statements:

1. The servo-control system advances the electrode for any electrode-to-workpiece machining voltage that is greater than the servo system's operational voltage range.
2. The servo system holds the electrode position stationary for any electrode-to-workpiece machining voltage in the acceptable servo system's operational voltage range.
3. The servo system retracts the electrode for any electrode-to-workpiece machining voltage that is less than the servo system's operational voltage range.

In actual operation, the machinist operates the servo-system control to bring the electrode closer to the workpiece surface. Should the electrode traverse during this procedure at a fairly fast feed rate to a point where sparking occurs, the servo system would not be able to stop the electrode advance quickly enough to maintain stable machining within the acceptable servo-control-voltage range. The electrode-to-workpiece machining voltage would then be in an unacceptable servo-voltage operational range, thus causing the electrode to advance again to the point of retraction. This oscillatory cycle would continue until the electrode servo-feed advance rate is reduced and the servo-control system takes command of the electrode feed when sparking occurs. This maintains the electrode-to-workpiece machining voltage in an acceptable servo-control range.

REFERENCE VOLTAGE FOR METALLIC AND GRAPHITE ELECTRODES

EDM-servo designers have found that the 30-VDC-reference voltage works well for metallic electrodes. But when graphite electrodes were introduced, it was found that this voltage could bring about an undesirable condition known as *DC arcing.* A higher reference voltage of 40 VDC was found to produce stable servo operating conditions and to reduce the possibility of DC arcing when using graphite material. This is why many power supplies include a graphite/metal switch to change the reference voltage to suit the electrode material used. Figure 7-4 shows the servo control's operational voltage ranges for the metallic and graphite electrodes.

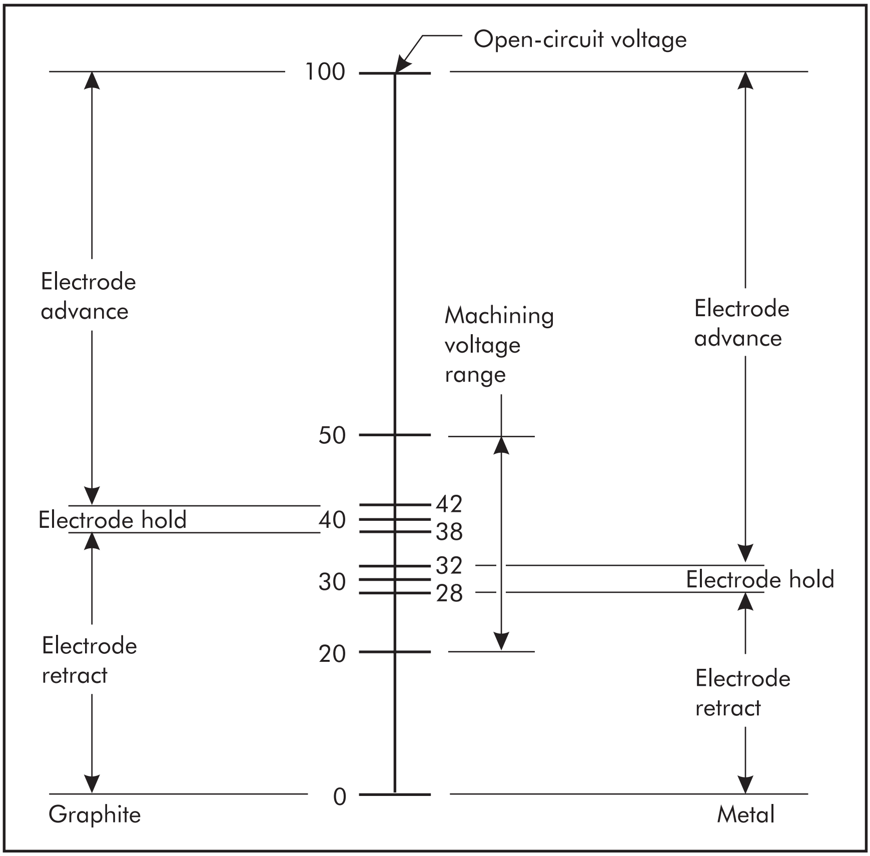


Figure 7-4. Metal and graphite servo-reference-voltage range.

SERVO-SYSTEM-VOLTAGE SENSING

The servo system is controlled by wires that connect the electrode and workpiece to the electronic assembly of the power supply. These sensing wires allow the electrode-to-workpiece voltage to be compared to the servo control's reference voltage. Figure 7-5 illustrates these electrical connections between the machine and power supply.

In the illustration, the servo's sensing wires and sparking-power leads connect to the electrode and workpiece. Since they connect to exactly the same place, servo engineers often connect the servo's sensing wires directly to the sparking-power-lead terminals within the power supply cabinet, thus eliminating the need for extra wires. However, not all servo-design engineers are in agreement with this practice. Some feel that separate servo sensing wires will more accurately convey electrode-to-workpiece voltage from the sparking gap to the servo's voltage reference unit. Since the end user is primarily interested in a stable operating servo system, the servo-system designer provides the type of servo sensing wire connections that are best suited to the servo system in use.

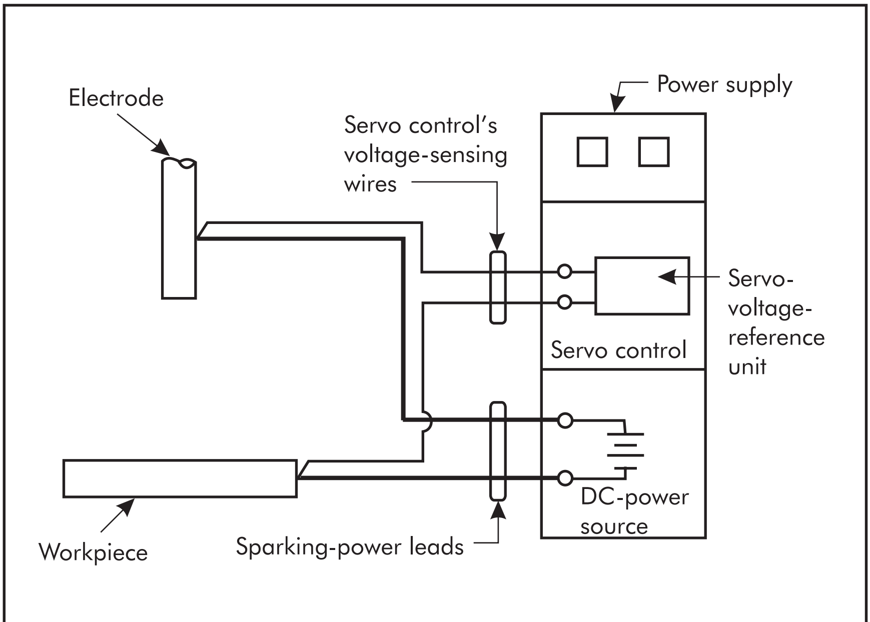


Figure 7-5. Electrical connections for sparking power and servo sensing.

ELECTRIC-MOTOR SERVO

Mechanically, the electric-motor and hydraulic-drive systems are simple structures. In both instances, the electronic control commands an action to be taken. The mechanical drive assembly advances, holds position, or retracts the electrode. Figure 7-6 shows a basic electric-motor servo-drive mechanical system.

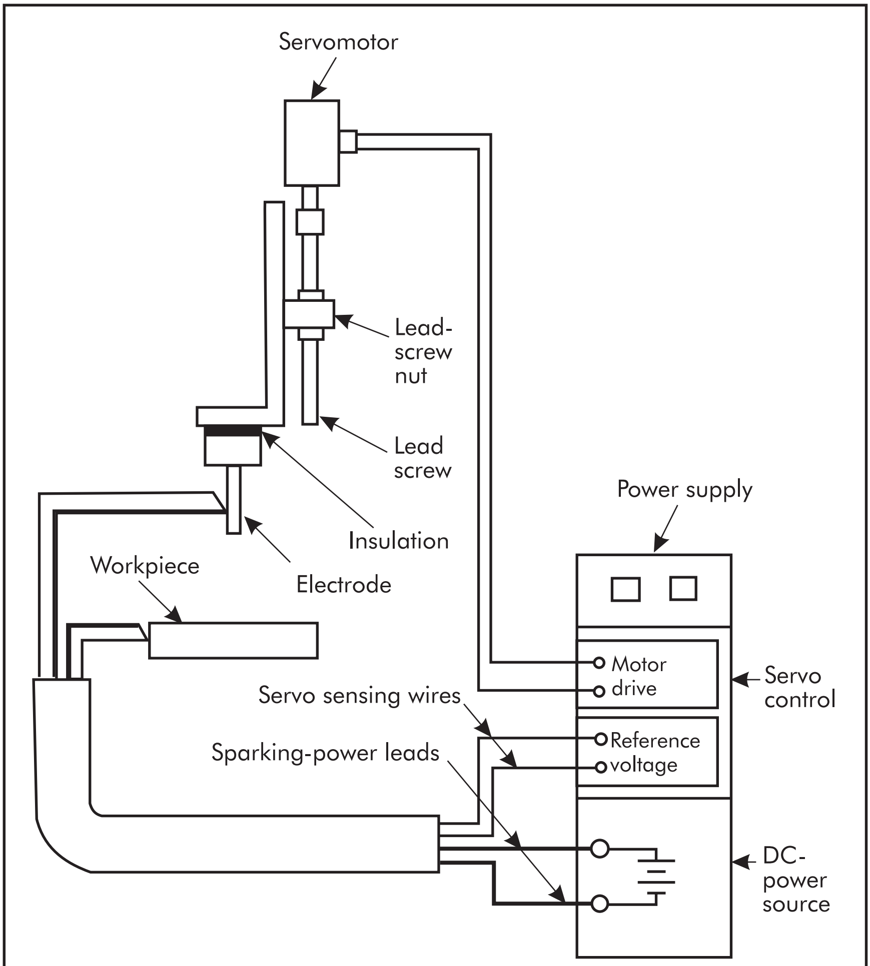


Figure 7-6. Basic electric-servo system.

The electric motor is directly coupled here to a precision lead screw. The lead-screw nut is attached to the machine axis of movement. There should be no backlash in the total drive system from the motor to the machine axis of movement where the electrode is attached. Any rotational movement of the motor will produce a corresponding movement in the machine axis and electrode. Should there be any backlash in this system, erratic servo action and unstable machining can result.

Many electric-motor-servo systems use pre-loaded ball screws to translate the rotational movement of the motor into the axial traverse required for electrode feed. Ball screws have anti-friction capabilities, allowing them to rotate freely without a force build-up prior to starting movement. This eliminates the possibility of the electrode jumping due to the motor exerting additional force to overcome a frictional force in the lead-screw assembly, prior to its electrode movement. The pre-load between the lead screw and nut also eliminates detrimental backlash in the drive assembly.

Any servo system used for EDM machining must be free of force build-up by the driving device, prior to the movement of the electrode carrier. Should the driving device apply a force without a corresponding movement of the electrode, the driver would continue to apply force until electrode movement takes place. This would cause the electrode to move excessively, and result in electrode retraction from a lower than acceptable electrode-to-workpiece voltage. Engineers refer to this condition as *stick friction*, since it results from the drive sticking in place until friction has been overcome.

HYDRAULIC SERVO SYSTEM

Hydraulic servo-drive systems are normally found on larger EDM machines because they are capable of supporting and controlling heavy electrode weights. This statement does not mean that hydraulic servo systems are not ever used on small- and mid-range EDM machines. The servo system used for any machine is always a choice of the design engineer. Hydraulic servos are capable of efficiently controlling any size of the EDM-servo system, with the exception of wire-cut EDM machines. Electric-motor-drive systems are preferred for wire-cut machines because positioning- and traverse-data-feedback devices are readily available. Feedback data is essential for optimum

operation of a computer-controlled servo system. Figure 7-7 illustrates a basic hydraulic servo system.

The hydraulic servo system is inherently backlash-free. When fluid pressure is applied to one side of the hydraulic-cylinder piston, fluid enters that side of the cylinder and exits the opposite side. The piston and piston rod move in response to the fluid entering the cylinder. When fluid is blocked from entering or leaving either side of the cylinder, the piston, piston rod, and attached electrode hold that position.

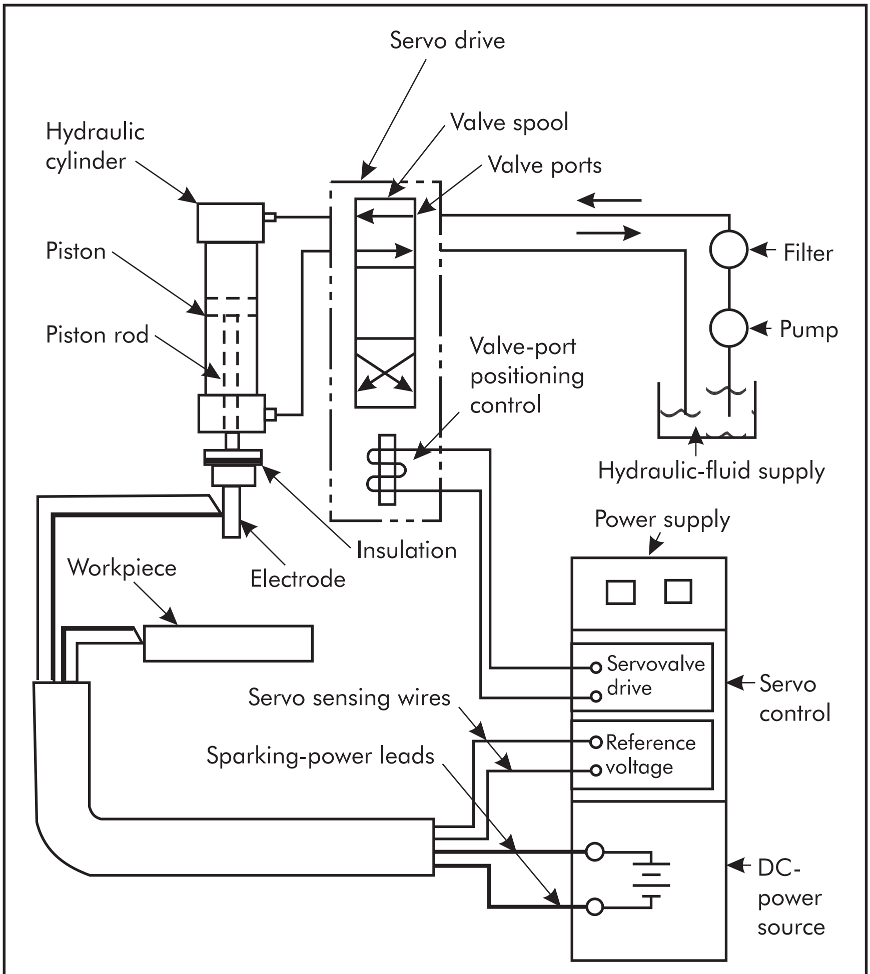


Figure 7-7. Basic hydraulic servo system.

The fluid flowing to and from the hydraulic cylinder is controlled by the servovalve, which is electronically controlled by the servo-control unit in the power-supply cabinet. Fluid flows through openings, or ports, in the servovalve. Electromagnetic or electronic positioning of the servovalve controls positioning of the ports for fluid flow. Port positioning results in three possible actions by the servo system:

1. Ports cause fluid to enter the hydraulic cylinder at the top. Fluid enters at the top and exits from the bottom. The electrode advances toward the workpiece.
2. Ports block fluid from entering or exiting either the top or bottom of the hydraulic cylinder. The electrode holds that position.
3. Ports cause fluid to enter the hydraulic cylinder from the bottom and exit from the top. The electrode retracts from the workpiece.

This illustration and description do not describe the design or the action of any particular hydraulic servovalve. They merely illustrate that an electronically controlled servovalve will efficiently produce the movement required to allow stable, efficient, machining action when a hydraulic cylinder is used.

When using a hydraulic servo system, the system should remain in a stationary position except when commanded to move by the servovalve. This is especially important if the hydraulic fluid changes temperature. Most hydraulic servo systems allow the valve to be adjusted for holding the system stationary, referred to as the *null* position. It is possible, however, for fluid conditions to change, affecting this *null* point, thus advancing the electrode toward or retracting it from the workpiece, without being under the servovalve's control. Should this process take place, the electrode may contact the workpiece or machine with enough force to damage the electrode, workpiece, and/or machine.

In most instances, electrode movement that is not under servovalve control is slow. This is referred to as *drift.* Recognizing this condition, EDM designers usually mechanically adjust the servovalve to create an up drift, which always causes the servo system to slowly retract the electrode from the workpiece. The machine manufacturer's instructions regarding the maintenance and adjustment of a hydraulic servovalve should be followed explicitly.

WIRE-CUT SERVO SYSTEM

The electric-motor drive is the servo system of choice for wire-cut machines. Since the electrode is always wire, electrode size and weight are not a normal consideration, compared to the coordination of multiple servomotor drives. Wire-cut servo systems are required to move a wire electrode through a programmed path that uses multiple servo drives to produce a shape in the workpiece. To accomplish this, a computer is programmed to control the multi-axis servo drives and to properly position the electrode wire as it moves through the workpiece to produce the machined form. Figure 7-8 illustrates the basic multi-axis wire-cut servo system.

Wire-cut servo-traverse speed is normally at a preset rate that is obtained from the computer-programming data. The wire-traverse speed is monitored so a continual comparison can be made between the electrode-to-workpiece machining voltage and the programmed reference voltage. Should the electrode-to-workpiece machining voltage be greater, the electrode wire's traverse speed will be automatically increased. This will bring the electrode wire closer to the workpiece and reduce the electrode-to-workpiece machining voltage so it is equal to the programmed reference voltage. Should the electrode-to-workpiece machining voltage be less than the programmed reference voltage, the servo-traverse speed will automatically be decreased to allow more distance between the electrode wire and the workpiece. This will raise the electrode-to-workpiece voltage and make it equal to the programmed reference voltage.

The wire-cut servo system is controlled by the data the machinist or programmer provides to the machine computer. For any particular application, the necessary data is entered to determine the machining parameters to be used. Application data required by the computer includes such items as:

- workpiece material, type and thickness;
- electrode material, type and diameter;
- final surface finish to be produced; and
- degree of accuracy required in the machined workpiece form.

With input of the required data, the computer produces a recommended set of machining parameters. This information is used for

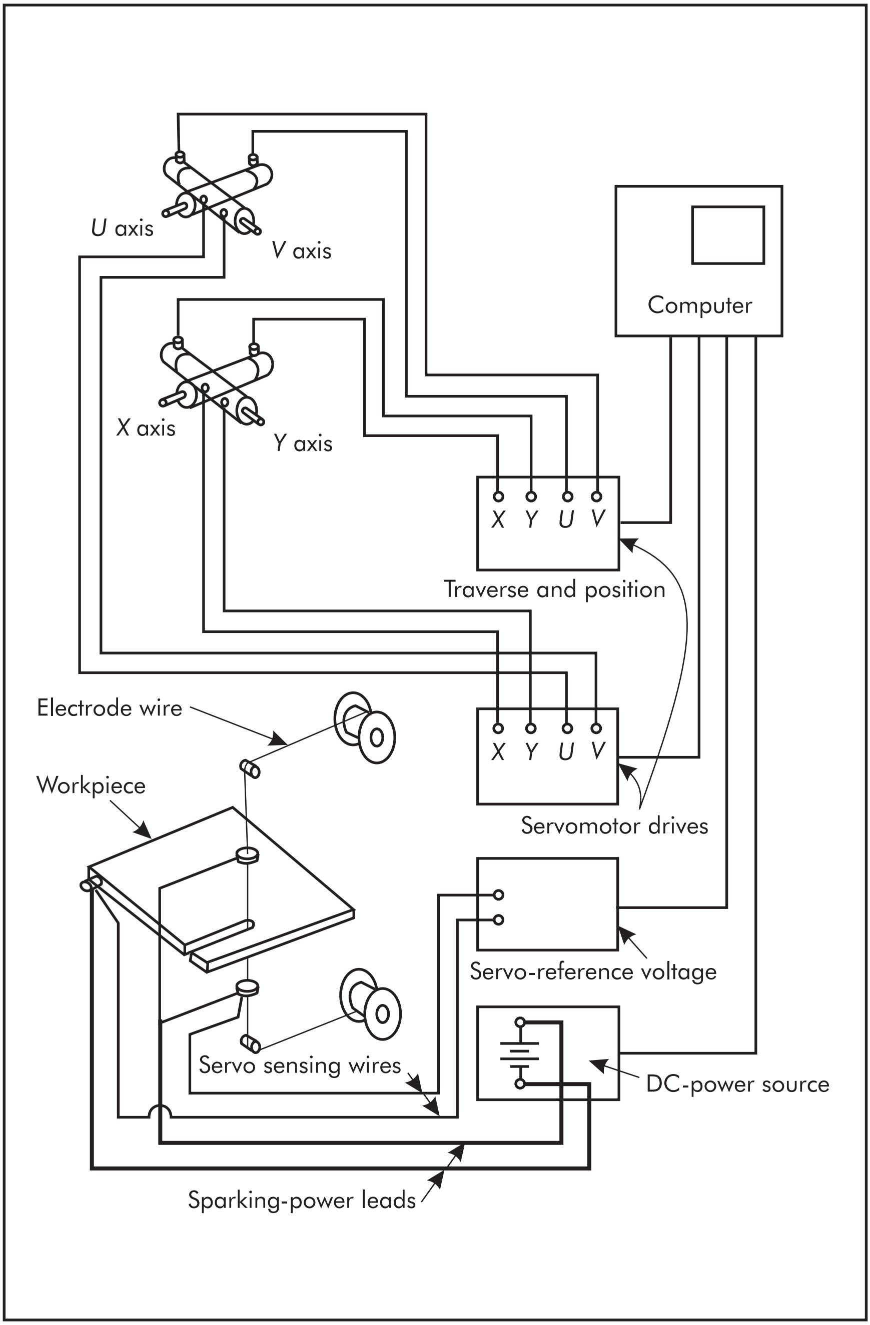


Figure 7-8. Basic multi-axis, wire-cut servo system.

machining the workpiece, unless it is modified by the machinist or programmer. Information provided from the computer database includes:

- machining amperes;
- machining voltage and electrode polarity;
- spark-ON and -OFF time;
- servo-traverse speed;
- wire-travel speed from the supply reel; and
- estimated servo-traverse speed for the machining operation.

SUMMARY

Servo operation of die-sinker- and wire-cut machine operations is very different. The operation of either type of servo system requires a certain amount of machine use experience. It is highly recommended that the machine user take advantage of training schools and application assistance offered by the manufacturer to gain knowledge and experience in the operation of either machine.

8 EDM Dielectric Systems

Previous chapters showed the relationship of EDM dielectric systems to the entire EDM process. This chapter will review and summarize the main points. It will also provide more detail on the functions and characteristics of the two kinds of dielectric systems used in EDM, along with warnings that should be exercised during use.

EDM DIELECTRIC FLUID

As a brief review, *Electrical Discharge Machining* (EDM) is defined as a process of machining electrically conductive materials with precisely controlled sparks in the presence of a dielectric material that is always a fluid. It is either usually a petroleum product or deionized water. Petroleum products are often referred to as *hydrocarbon fluids,* since they break down into hydrogen, carbon, and other by-products when they are heated during sparking. Deionized water has the impurities removed that would make it electrically conductive. The heat of sparking breaks down this water into hydrogen and oxygen. Usually, die-sinker machines use hydrocarbon dielectric fluids, and wire-cut machines use deionized water. However, some wire-cut machines are designed to use hydrocarbon fluids.

HYDROCARBON FLUIDS

Fluids are used as dielectric material because they are readily available and they provide a controlled environment to surround the sparking area. Hydrocarbon fluids maintain their dielectric characteristics during the sparking process when sparking heat breaks the fluid down, and the machining process adds debris. This electrical integrity under such conditions makes hydrocarbon fluids the dielectric fluid of choice for submerged machining.

DEIONIZED WATER

Deionized water absorbs materials that make the water electrically conductive during the sparking process. As water absorbs materials, the dielectric characteristics of the water change. This also changes the water's ionization point and it affects the reliability and repeatability of the sparking process. Given these facts, it would appear that deionized water is not an acceptable dielectric fluid. But wire-cut EDM uses dielectric fluid differently than die-sinker EDM. In most instances, wire-cut-machining operations are not performed with the workpiece submerged. Instead, a high-velocity flow of fresh deionized water surrounds the electrode and covers the workpiece in the sparking area. It then returns immediately to the collection system for reprocessing. This process ensures that the deionized water passing through the sparking area will stay within the acceptable range of electrical characteristics required for precise EDM operations. In addition, it makes deionized water the dielectric fluid of choice for wire-cut operations.

DIELECTRIC-FLUID FUNCTIONS

EDM dielectric fluids perform four functions necessary for spark machining. The fluids provide:

1. a known electrical barrier between the electrode and workpiece;
2. cooling for the electrode and workpiece;
3. cooling for the vaporized material that becomes the EDM chip upon solidification; and
4. a means for removal of the EDM-spark debris from the sparking gap.

Dielectric-fluid Description

EDM *dielectric fluid* is an electrical insulator that resists the flow of electricity, until voltage high enough to cause the fluid to change into an electrical conductor is applied. The point when the fluid changes from an insulator into a conductor is called the *ionization point*. At the point of ionization, electricity, in the form of a spark, readily flows through the dielectric fluid between the electrode and workpiece.

Spark-ON time determines how long spark electricity will flow after the ionization point is reached. When spark electricity is turned OFF,

electricity stops flowing. The spark is then extinguished and the dielectric fluid is once again an insulator. This characteristic is most important, since the dielectric-fluid-ionization point controls each spark. These changes, from insulator, to conductor, to insulator, take place for each spark. It is possible for this action to occur as often as 500,000 times per second (500 kHz).

Electrode and Workpiece Cooling

As spark electricity flows between the electrode, and as the workpiece heat is generated, heat is dispersed within the electrode and workpiece material. The dielectric fluid helps remove this heat as it surrounds the sparking area. With proper containment of the dielectric fluid, the temperatures of the electrode and workpiece are only warm to the touch. The high temperature of spark heating, however, still affects the sparking surfaces of the electrode and workpiece. The workpiece/electrode sparking heat in this process is transported away from the sparking gap through the material and dielectric fluid. Sometimes cooling the dielectric fluid is recommended. For instance, wire-cut machines using deionized water and die-sinker machines with high amperes often need to cool the fluid.

EDM Chip Cooling

As each spark occurs, the workpiece/electrode material is heated until it vaporizes and collects into a cloud in the sparking-gap area. Heat from the vapor cloud is transferred to the dielectric fluid. The vapor then cools and solidifies. Cooling of the vapor cloud starts on the outside and proceeds to the inside. This produces a sphere with a hollow center known as the *EDM chip*.

EDM Chip Removal

EDM chips must be removed from the sparking area, ideally, at the same rate they are generated. This allows a constant population of chips in the sparking gap and it contributes to the stable operation of the servo system. A number of methods have been developed for using dielectric fluid to remove chips. In all instances, the principal

concern is to have dielectric fluid flow through the sparking gap and then transport chips out of the sparking area. The chips are carried along in the dielectric fluid to a collection and filtration system. This system removes the chips and other EDM-sparking debris from the fluid. In addition, it reprocesses the water to ensure acceptable dielectric qualities prior to reuse.

Fluid Viscosity

Low viscosity is a desirable quality in a dielectric fluid, because it helps fluid flow more readily through the sparking gap. Very small sparking gaps are encountered in low-ampere, high-spark-frequency machining operations, such as fine-finish machining. EDM-machine manufacturers specify the correct dielectric fluid that is needed to produce acceptable machine operation over a wide range of machining needs.

It is possible for a low-viscosity, hydrocarbon dielectric fluid to have a low flash point. Caution is advised when using any low flash-point fluid, since the possibility of combustion exists.

DIELECTRIC FLUID BY-PRODUCTS

As mentioned before, EDM sparking heats the hydrocarbon dielectric fluid to a point that causes the fluid to break down into hydrogen and carbon. This breakdown during sparking creates smoke, containing a mist of oil, to rise above the fluid surface.

Smoke Removal

It is important to remove smoke by-products from the machining area to protect the machinist and other workers. Safety data published by the dielectric-fluid manufacturer should also be posted in the machining area.

Oil-mist Deposit and Fire Possibility

Many EDM-power supplies use the surrounding environment for cooling air. Should this air include oil mist, the mist will be taken into

the power supply and deposited on the electronic components. Over time, the oil mist builds up as a deposit of oil that collects dust and eventually causes electronic components to fail. It is possible for the electronic components to overheat and cause the oil/dust material to burst into flames.

Hydrogen Ignition Possibility

Hydrogen gas is a by-product of both hydrocarbon fluid and deionized water. This gas needs to be exhausted from the machining area, making sure that points or chambers where it could collect are not allowed to exist. This is because hydrogen can be ignited by open flames or even by exposed EDM sparking.

Dielectric Fluids and the Environment

After a long service life, it is important to correctly dispose of EDM dielectric fluid. Materials machined while this fluid is in use also require proper disposal. This is because the dielectric fluid may still contain EDM chips and debris, materials that may not be acceptable as normal waste material.

Water Corrosion

A mist is given off when using a deionized-water dielectric. Although wire-cut machines are fabricated from materials that resist corrosion from such water vapor, machines in close proximity are still vulnerable to rusting. For this reason, wire-cut machines are often housed in separate rooms with controlled environments. In addition, care is exercised to ensure that water vapor does not enter the electrical, electronic, or computer enclosures of the machine, since this could cause damage to the components.

FUME EXTRACTION, DUST COLLECTION, AND FIRE POSSIBILITY

When a fume-extraction system is used to remove hydrocarbon byproducts, it should include a fire extinguishing system that is properly

maintained at all times. As fumes are extracted, an oil-mist residue is deposited on the surfaces of the exhaust system. This residue attracts dust particles from the air. Should gas in the smoke or dielectric fluid ignite, the fire could spread to the exhaust system. If this fire is not put out immediately, the oil-mist-residue deposits could burst into flames. And, since dust particles can function like a wick, the fire is likely to spread. Once a fire has started in an exhaust system, it is difficult to extinguish.

Fire Precautions with Hydrocarbon Fluid

All hydrocarbon dielectric fluid should be considered combustible. When precautions are observed, the possibility of a fire is minimal. But things such as keeping an insufficient amount of dielectric fluid above the sparking area must always be avoided. All EDM manufacturers should discuss any safety concerns at the time of machine installation and in training schools.

Most EDM manufacturers recommend having trained personnel in the immediate vicinity of EDM operations that involve hydrocarbon fluids. In most instances, if flaming is observed in the sparking area, immediate actuation of the emergency-stop switch will shut down the machine and normally extinguish the flame. If the fire continues after the machine has been shut down, emergency fire extinguishing operations should be immediately enacted.

DIELECTRIC-FLUID SERVICE LIFE

Dielectric fluid must be added to the system on a regular basis because it is lost in two ways. The fluid is lost when it evaporates. It is also lost when it is carried away with the machined parts. By adding fluid, the electrical characteristics required for proper ionization over long time periods are normally maintained.

There are conditions, however, that merit the testing or replacing of fluid, including:

- when the machine has been inactive for long periods of time;
- when machining operations are performed at high dielectric-fluid temperatures; and/or
- when the dielectric fluid is contaminated.

HEALTH CONSIDERATIONS

Breathing of vapors and fumes is not recommended when working with dielectric fluids. Although dermatitis and skin irritation can occur in this instance, the conditions are rare when good personal-hygiene procedures are followed. However, if a worker experiences any health problems, proper medical care should be obtained at once, and the manufacturer of the dielectric fluid should also be contacted immediately.

DIELECTRIC FLUID'S EFFECT ON SYSTEM COMPONENTS

It is possible when changing from one dielectric fluid to another that undesirable effects on machine components may be experienced. Some fluids may remove material from plastic material and cause premature failure. Materials in some dielectric fluids may also affect pump seals, gaskets, and hoses. The machine manufacturer should be consulted prior to changing dielectric fluid.

DIELECTRIC FILL-DRAIN SYSTEMS

There are a number of different dielectric fill-drain systems used on EDM machines. Since die-sinker machines normally submerse the workpiece, the dielectric fluid must be drained away from the work area during setup and inspection operations of the work area. Removal of the dielectric fluid from the work area is usually accomplished in one of two ways:

1. by draining the fluid into a storage reservoir; or
2. by using a retracting work tank that lowers the fluid as the tank retracts into the machine base.

The retracting work-tank design offers a major benefit. This is because the entire work area opens for workpiece setup and inspection as the work tank retracts. However, the retracting work tank requires additional components for the retracting mechanism. Support for the worktable must be considered since the machine structure must allow retraction of the work tank assembly into the machine base. The retracting work tank normally requires the machine to be designed with

the *X-Y* positioning included in the machine-head assembly, rather than through an *X-Y*-positioning table. The remainder of the machine design, with the exception of the retractable work-tank assembly, is similar to an assembly using an open-reservoir fill-drain system.

DIE-SINKER OPEN-RESERVOIR FILL-DRAIN SYSTEM

Most die-sinker EDM machines use the open-reservoir fill-drain system. Figure 8-1 illustrates a typical open-reservoir design.

Dielectric fluid is stored in a reservoir that can be separate from or included in the machine base. Using a pump, fluid is transferred from the reservoir to the machine's work tank. This pump is normally a centrifugal design, capable of pumping abrasive material. The fluid in the reservoir contains EDM chips that flow with the fluid as the work tank drains. These EDM chips are abrasive and will cause excessive wear on pump components that are not designed to handle abrasive materials.

Starting the fill pump and opening the fill-drain valve causes unfiltered dielectric fluid to be pumped from the reservoir and into the work tank to the desired fluid level. The fill-drain valve is then closed. The overflow standpipe is adjusted here to maintain the required level and allow the overflow of excess fluid to drain back into the reservoir.

Prior to starting the EDM operations, a second pump is started to accomplish chip removal in the sparking area. This pump must also be capable of passing abrasive EDM chips. This is because the pump uses the unfiltered fluid that is left in the reservoir after the work tank is filled. This pressure pump forces the fluid through a filter to remove both the EDM chips and the debris in the fluid to prevent them from passing through the sparking gap. Filtered fluid then is provided to the electrode and the sparking gap. The fluid flow through the electrode is controlled by an adjusting valve that allows it to bypass the electrode and go directly into the work tank. Dielectric-fluid pressure to the electrode is monitored by a pressure gage. As the bypass valve is closed, the electrode pressure raises and more fluid flows through the electrode. Fluid flow through the electrode is adjusted to remove EDM chips at approximately the same rate they are generated by the spark frequency. The stability of the servo-drive system will be affected if

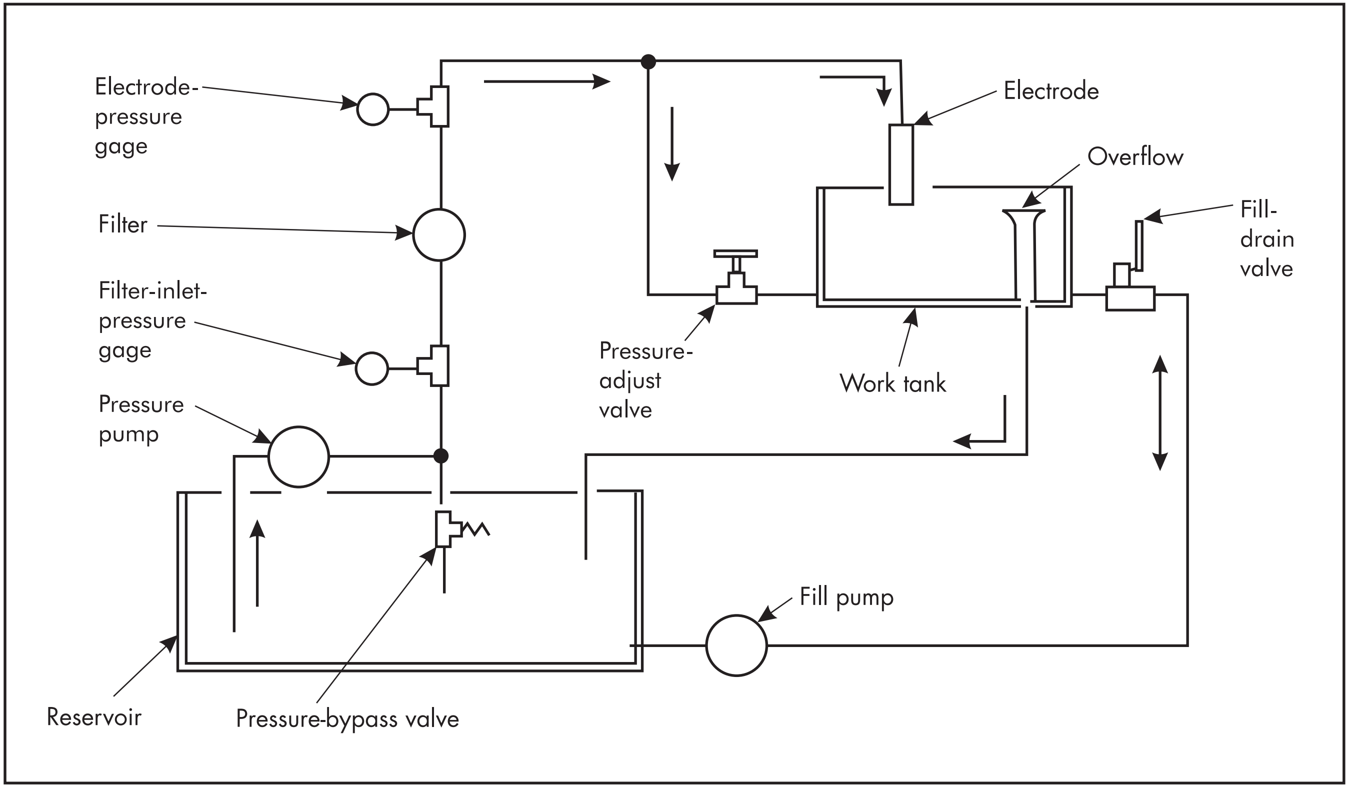


Figure 8-1. Open-reservoir fill-drain system.

proper fluid flow is not provided through the sparking gap. Fluid supplied to the electrode is in addition to that used for filling the work tank. The overflow allows excess fluid to return to the reservoir without overflowing the work tank.

The pressure-pump system includes a pressure bypass valve that is set so the pressure prevents system damage in the event of a blockage. If the fluid filter becomes clogged with chips and debris, pressure can increase to the point of rupturing the filter. The bypass valve is set to bypass fluid back to the reservoir at a pressure that does not allow damage to the system's components.

A pressure gage is included between the pressure-pump output and filter input. There is another pressure gage between the filter output and the electrode. The first gage indicates the pressure applied to the filter element. The second gage indicates pressure at the electrode. Many manufacturers determine the time for filter-element changes by comparing the filter-input/output pressure readings on these gages. Filter-input pressure increases as the filter element becomes clogged. When it increases above the output pressure, a point is reached where the filter element requires changing.

Upon completion of the EDM cycle, or at any time it is necessary to lower the fluid in the work tank, the fluid must be drained back into the reservoir. This is accomplished by opening the fill-drain valve and allowing the fluid to flow through the fill pump and back into the reservoir. In many machine designs, this pump is centrifugal to allow a reverse flow of fluid through the pump. Reverse fluid flow must be done with the pump motor turned off.

The following information relates to open-reservoir fill-drain systems:

1. When unfiltered dielectric fluid fills the work tank, it can affect the machinist's ability to observe the work area. This is because the view is obstructed by debris that is held in suspension by the unfiltered fluid.
2. Even though fluid in the work tank is unfiltered, filtered fluid is provided to the sparking gap.
3. Unfiltered work-tank fluid causes chips and debris to settle during machining. This accumulation creates a need for regular work-tank clean up.

DIE-SINKER CLOSED-RESERVOIR FILL-DRAIN SYSTEM

The closed-reservoir fill-drain system's operation is almost identical to the open-reservoir system, except in the following ways:

- The closed tank is sealed, as opposed to open, to prevent escape of dielectric fluid and compressed air.
- No work-tank-overflow standpipe is required with the closed reservoir system.
- The closed system does not require a fill pump.

Figure 8-2 shows the sealed- or closed-reservoir fill-drain system. Here, compressed air supplied to the sealed reservoir fills the work tank. This air causes the dielectric fluid in the reservoir to be displaced and flow through the fill-drain hose and into the work tank. After the desired amount of fluid is forced from the reservoir to the work tank, the fill-drain valve is actuated to prevent the escape of compressed air from the reservoir. Equilibrium is then established between the displaced reservoir fluid and the compressed air in the reservoir. The fill-drain hose does not have a valve. This is because the fluid level in the reservoir is maintained when air pressure is applied.

Filling the work tank, holding the fluid level, and draining the work tank are all tasks that are accomplished through the fill-drain valve. The three positions of this valve are:

1. Fill position: the compressed air enters the reservoir and causes the fluid to flow into the work tank.
2. Hold position: the air inlet to the reservoir is closed and the volume of compressed air in the reservoir is maintained.
3. Drain position: the compressed air in the reservoir is allowed to escape into the atmosphere. As the air is released, the fluid in the work tank drains back into the reservoir.

Considerations for this system, in addition to those mentioned for the open-reservoir system, center on the reservoir and compressed-air quality. They include:

- The reservoir in operation is a closed vessel. If the outlet becomes plugged, compressed air may be applied to the point of causing the reservoir to fail. Some manufacturers include preset air-escape valves that release air if pressure rises above a certain value.

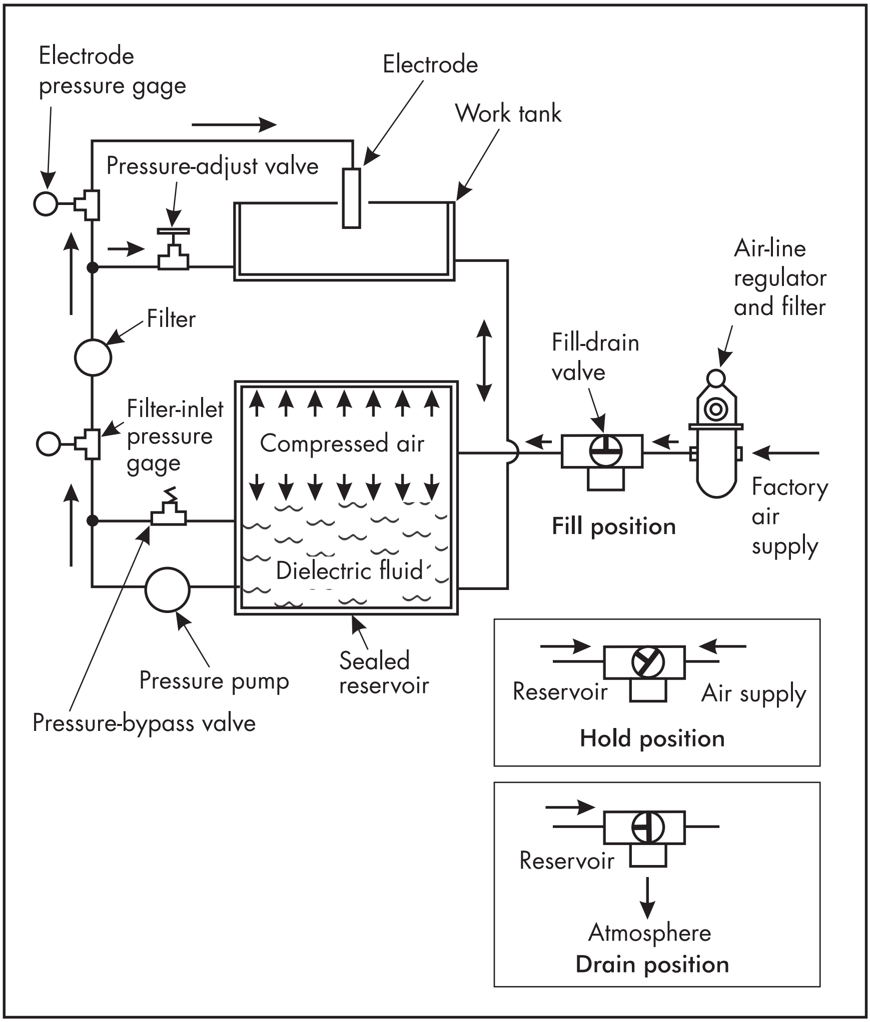


Figure 8-2. Closed-reservoir fill-drain system.

- Compressed air must be moisture free, since moisture could collect in the reservoir over a period of time. (Water is detrimental to the dielectric-fluid quality and it may cause machine components to rust.)
- The compressed-air supply should be regulated so it does not exceed the reservoir's pressure rating.

- The reservoir is normally included as a sealed unit as part of the machine-base assembly. Build-up of EDM chips and debris over a period of time is not obvious. It is important, therefore, to open the sealed inspection plate to access the reservoir for removal of debris. This should be done according to manufacturer recommendations. In addition, this inspection plate must be resealed securely to prevent leakage of dielectric fluid.
- The reservoir must also be sealed to prevent air leakage. If compressed air leaks from the reservoir during EDM operations, the fluid level in the work tank will be lowered. Should the fluid level lower enough to expose sparking, it could ignite.

DIE-SINKER FILTERED/UNFILTERED-RESERVOIR FILL-DRAIN SYSTEM

Figure 8-3 illustrates the filtered/unfiltered fill-drain system. This system is an extension of the open-reservoir system, with the addition of a reservoir that contains filtered dielectric fluid. Dielectric filtration in this system is continuous, even when machining is not taking place. All fluid used for filling the work tank and maintaining the pressure flow to the electrode is filtered. This can reduce the quantity of EDM chips and the amount of sparking debris settling out of the work-tank fluid during machining. Filtered fluid can also allow better viewing of the machining. But, filtered fluid does not ensure that it will remain clear during the machining operation. EDM chips and debris are removed from the sparking gap by fluid flow. This debris is present during machining and it settles out of the fluid and into the work tank. During high-ampere machining, the amount of chips and debris in the work tank can be considerable. Having filtered dielectric fluid in the work tank is a requirement when using vacuum flow for EDM chip removal since work-tank fluid is used for chip removal.

Since filtered/unfiltered reservoir systems allow continuous filtration of the fluid, it is possible to filter the fluid to a point that the filtered reservoir overflows. To prevent this, the separating partition between reservoirs is designed to allow filtered fluid to flow over the partition and back into the unfiltered reservoir. When this occurs, the filtered fluid mixes with the unfiltered fluid and, once again, goes through the filtration process. Float switches can be installed in both reservoirs to monitor fluid levels. A low level in the unfiltered reservoir

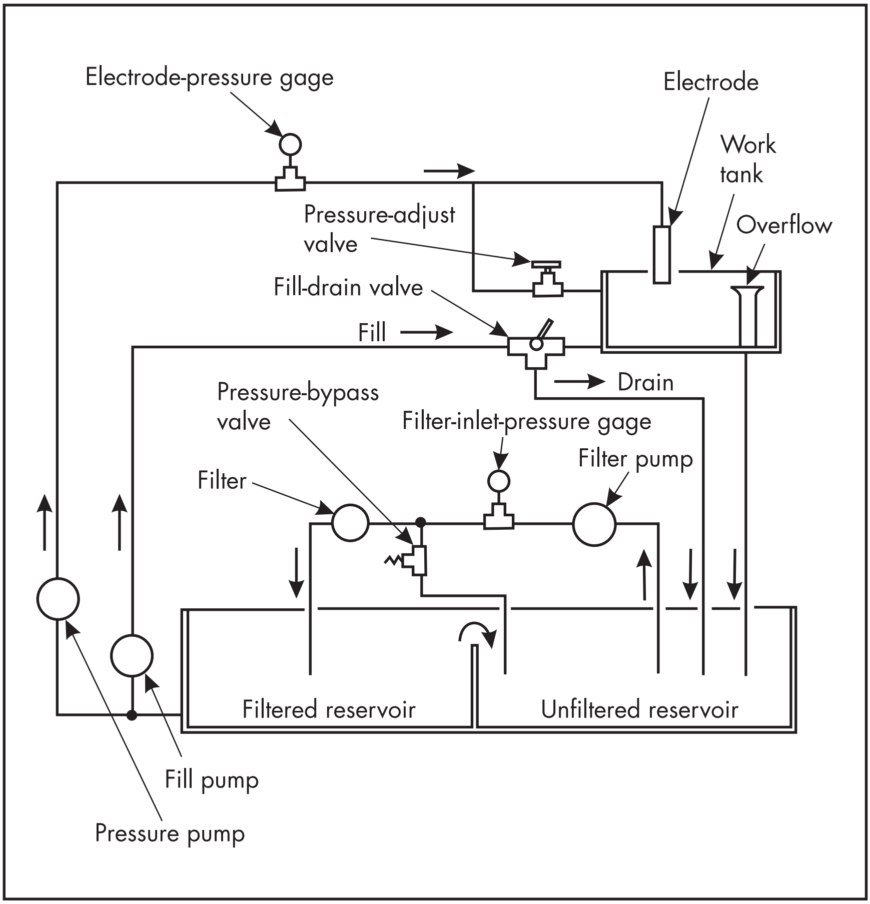


Figure 8-3. Filtered/unfiltered-reservoir fill-drain system.

stops the filtration pump and a low level in the filtered reservoir terminates the machining cycle.

WIRE-CUT DEIONIZED-WATER SYSTEM

Wire-cut deionized-water systems are designed to assure the electrical quality of water provided to the sparking area. Deionized water is very corrosive, so all system components must be appropriately designed. It is always necessary to perform proper maintenance on the

system, since the deionized water is easily contaminated. Figure 8-4 illustrates a typical deionized water system.

After the deionized water passes through the sparking gap, it is collected and returns to the unfiltered reservoir. Water in the unfiltered reservoir contains EDM chips and dissolved material that was absorbed as it passed through the sparking area. The water is pumped from the unfiltered reservoir through filters that remove the solid materials and then into the filtered reservoir.

Water Conductivity

Water in the filtered reservoir is monitored for electrical conductivity. When the water quality is reduced to a preset point, it is pumped through a deionizer unit that removes the dissolved materials and impurities that cause it to be an electrical conductor rather than a dielectric fluid. After processing the water through the deionizer, it is returned to the filtered reservoir for use in the EDM process.

Water Temperature

Water temperature is controlled in most wire-cut machines. This assures consistent accuracy for water-quality testing. In most instances, water temperature is stabilized at approximately 68° F (20° C), or normal room temperature. This temperature maintains the thermal stability of the machine and workpiece under normal working conditions. It also reduces the problem of condensation that is caused by different room and water temperatures.

Water that is filtered, temperature-controlled, and reconditioned is pumped to the machine's upper- and lower-flushing nozzles. Flow-control valves direct the flow to each of these nozzles. Nozzle flow is adjusted to allow the water to completely surround the electrode wire in the sparking area. The nozzle-flow-control valves can be manually operated or adjusted by computer. In addition to removing EDM chips and providing dielectric qualities, the water provides cooling for the electrode wire, the workpiece, and the wire's electrical contacts. When the wire-cut machine has an automatic wire-threading system, water is often used to transport wire through the automatic threading mechanism.

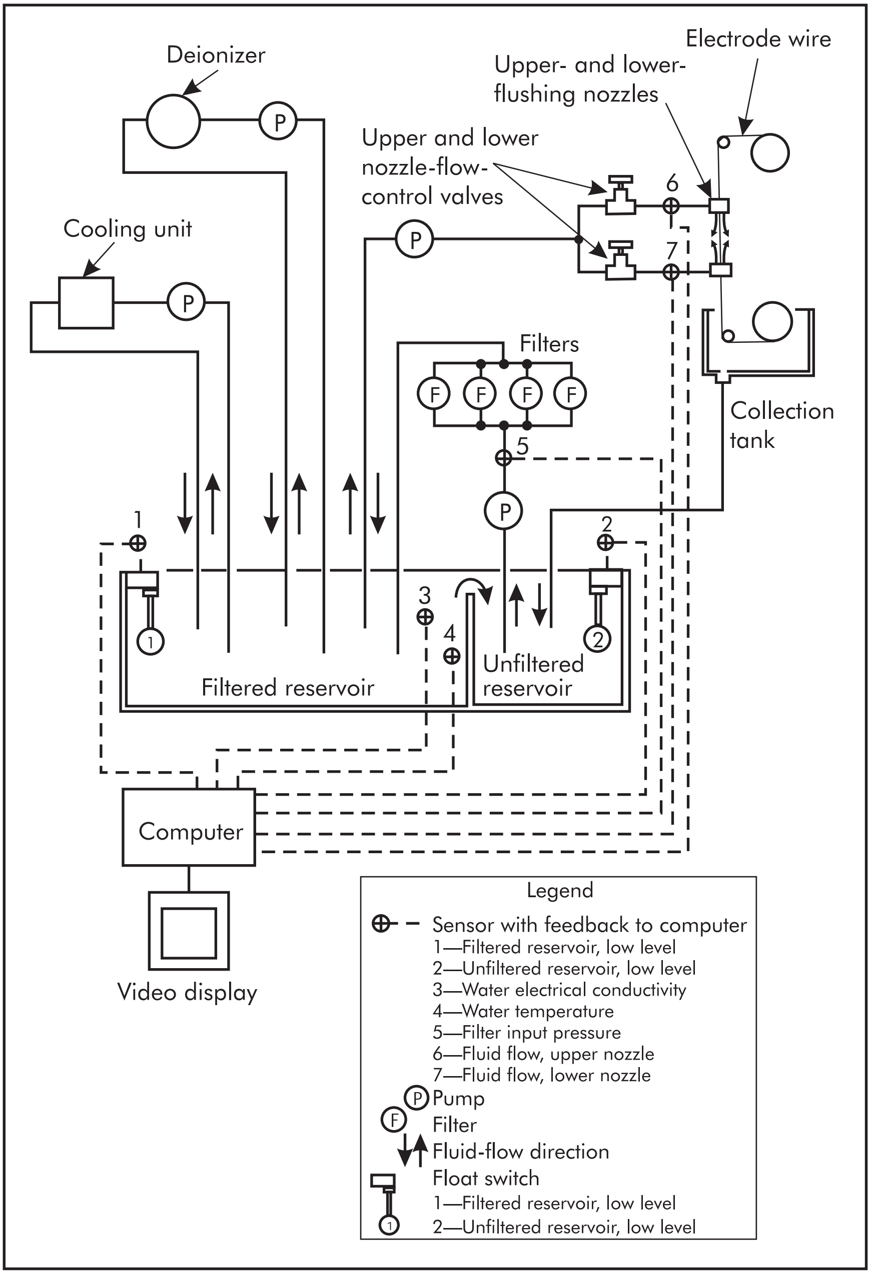


Figure 8-4. Wire-cut deionized-water system.

Computer Monitoring of Water System

Computer control of wire-cut machines allows monitoring of the deionized-water system and ensures that water quality, temperature, and flow rates stay within acceptable limits. Information is displayed on a video monitor. If any monitored item reaches an unacceptable limit, a correction may be initiated or the machining cycle may be terminated.

Typical video-monitor displays include:

- Float switch #1: low-fluid level, filtered reservoir. Stop machining cycle.
- Float switch #2: low-fluid level, unfiltered reservoir. Add water.
- Filters: high-input pressure. Service filter elements.
- Deionizer unit indicator displays:
  - Water quality acceptable.
  - Pump ON (while water is being reconditioned).
  - Warning: water quality less than acceptable limit. (Under this warning, the present machining cycle may not be terminated, but the start of the next machining cycle may not be possible until a correction has been made.)
- Water temperature displays:
  - Actual temperature.
  - Temperature is within acceptable range.
  - Warning: temperature exceeds acceptable limit.

The float switch in the unfiltered reservoir controls the fluid flow through filters. As water returns from the machine, the fluid level rises; the float switch is actuated; and the filter pump is turned ON. As the pump processes the water through the filters, the level of the fluid in the unfiltered reservoir may drop. If this occurs, the float switch opens and the filter pump turns OFF. It is also possible for the fluid in the filtered reservoir to overflow as the fluid is transferred from the unfiltered reservoir into the filtered reservoir. To prevent the filtered reservoir's overflow, the partition between the reservoirs is designed so that it is lower than the reservoir sides. This allows excess fluid to flow back into the unfiltered reservoir.

Deionized Water—Use Considerations

The following information relates to using a deionized-water dielectric system.

- The deionizer unit removes dissolved material from water. This material then collects in the unit, diminishing the capability of the deionizer to produce acceptable water quality. At some point, the deionizer material must be replaced.
- A process known as *ion exchange* deionizes water. This process requires the use of a resin material. When replacing the deionizer unit, the used material must be disposed of in accordance with environmental requirements.
- Water from the factory source may not be acceptable for filling or replacing water for the deionized-water system. It may be necessary to obtain pre-deionized water.
- Bacteria and fungus can grow in the system and cause problems with the deionizer unit and filters. If this happens, the system might have to be purged and cleaned before acceptable water can be produced.
- Machine manufacturer recommendations should always be observed in setting up, using, and maintaining a deionized-water-dielectric system.

FILTRATION

Dielectric fluid needs to be filtered to remove EDM chips and byproducts that are produced during sparking. The filter assembly provided with most EDM machines consists of a canister that contains the filter with a replaceable element. When the element becomes clogged and fluid flow through the filter is restricted, the element is removed and replaced.

Disposal of the used filter must be in accordance with proper environmental considerations. It is a good policy for filter elements used with hydrocarbon fluids, to drain the fluid from the element prior to disposal. The salvaged fluid can be returned to the machine's dielectric system.

Filters do not completely remove all particles from the fluid. Filter elements are rated in microns according to their level of filtration.

Elements supplied for EDM filtration normally fall within a range of 5–20 microns. This rating indicates that the filter, when new, removes particles larger than the micron-rating size. Particles of the rated size and smaller will pass through the filter element. Figure 8-5 illustrates particles smaller than the micron-rating size passing through the filter element, and particles larger than the micron rating collecting at the filter-element surface.

As the filter is used, even the small passages become clogged with debris. Dielectric flow through the filter is then restricted and the filter element must be replaced to obtain required fluid flow.

FILTER LIFE BASED ON AMPERE HOURS

Some filter-element suppliers provide estimated life expectancies, in addition to the filtration-micron rating, for their filter elements. Expected life is provided as an ampere-hour rating and it is based on the filter's surface area and on the type of dielectric fluid used. For example, if a filter element is rated at 100-ampere hours, the expected service life is one hour when machining at 100 amperes, or 100 hours when machining at one ampere. Ratings are only estimates, since the electrode and workpiece materials used also affect the actual life of the filter element.

EDM-machine manufacturers most often use a comparison of the filter-inlet to the filter-output pressure when determining if the filter element should be replaced. Figure 8-6 illustrates the placement of filter-pressure gages to measure these pressures.

If there were no restrictions to the dielectric-fluid flow by the filter element, both the inlet- and output-pressure gages would display the same pressure. But, as particles begin to clog the filter, the passage of fluid through the element becomes restricted, causing the inlet pressure to increase due to the force exerted to move the fluid through the filter. When the inlet pressure exceeds the output pressure by the amount determined by the EDM-machine manufacturer, the filter is sufficiently clogged to warrant changing.

In many instances, EDM manufacturers include a pressure-bypass valve between the pressure pump and filter to divert the fluid flow back into the dielectric reservoir if the filter system becomes blocked. The bypass valve is set at a pressure that will bypass fluid before damaging the filter-system components.

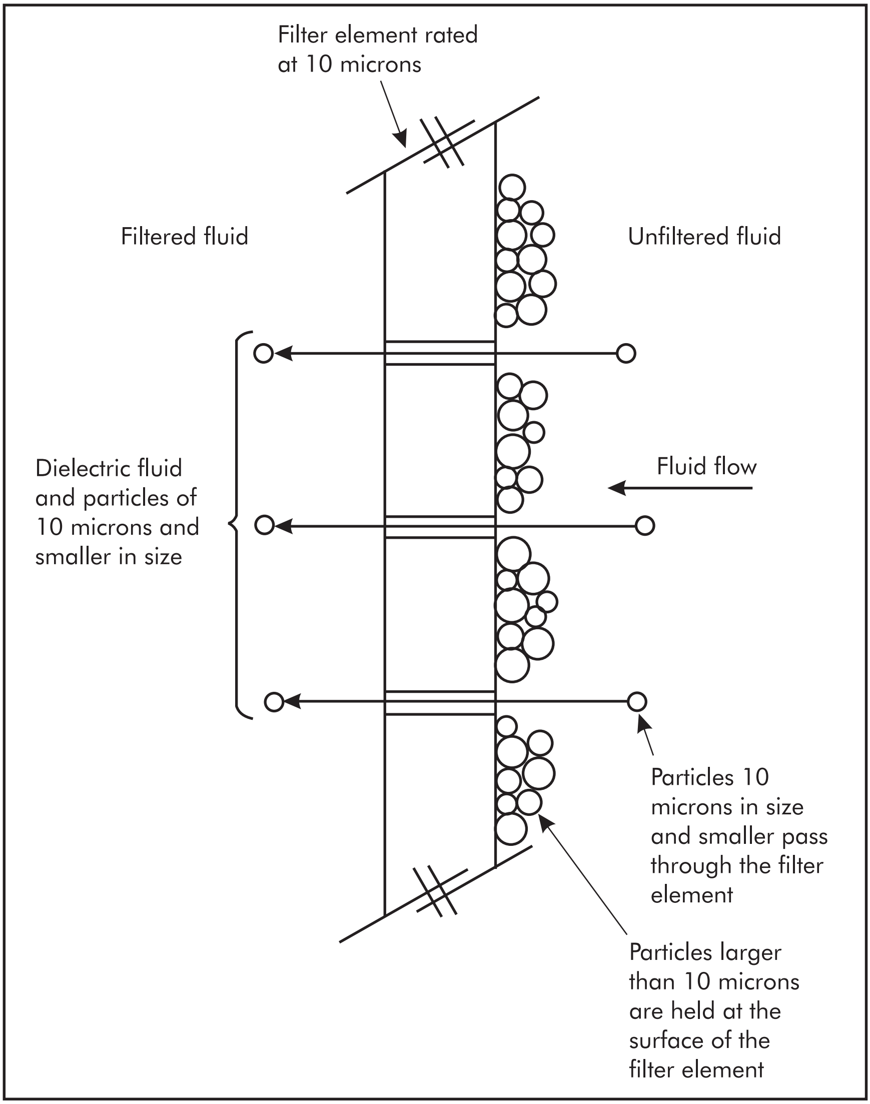


Figure 8-5. Filtration based on filter-micron rating.

After filter-element replacement, any trapped air in the filter vessel must be released to assure that the complete filter-element surface is exposed to the dielectric-fluid flow. Venting, or allowing the trapped air to escape, is normally accomplished by opening a valve, or petcock, while the dielectric system is in operation. When the air flow stops and

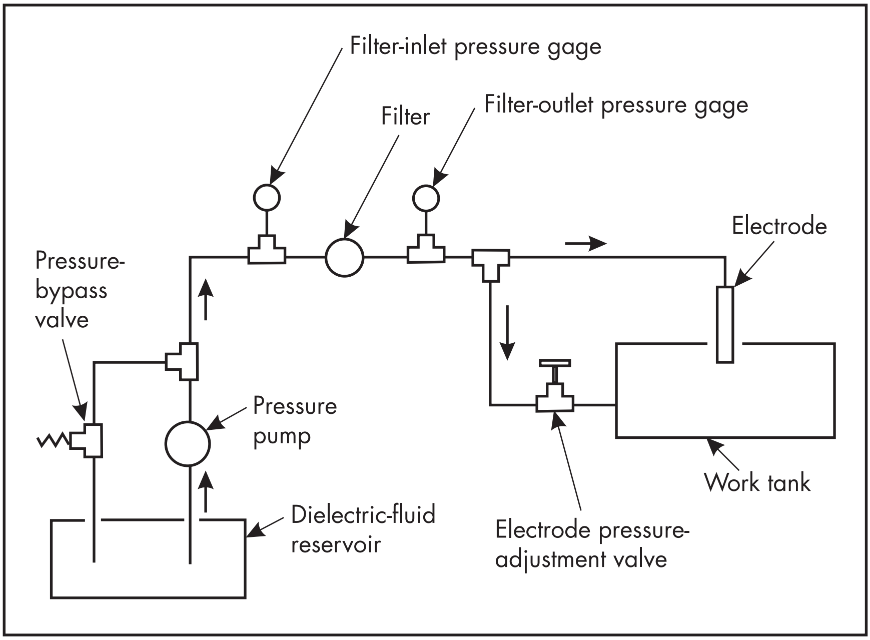


Figure 8-6. Pressures determine filter replacement time.

fluid starts flowing from the valve, venting is complete and the valve is closed for normal filter operation. Care should be exercised when venting the filter vessel, because the air is compressed and may include a dielectric-fluid mist.

CENTRAL-FILTRATION SYSTEMS

The need for filter-element change may come at an inconvenient time for the EDM machinist or for the maintenance personnel. It may be practical, therefore, to add a second filter unit. The second unit is maintained on standby until the primary unit requires maintenance. At that point, the second filter unit is placed into immediate service. The primary unit is deactivated and serviced at a convenient time and then remains on standby until the second unit requires maintenance. Employing a two-unit method of filter maintenance allows EDM operation to continue without stoppage.

When multiple EDM machines are in use in a common area, a central-filtration system, common to all the machines, may be worthwhile.

However, the possibility of that system failing, rendering the entire group of machines inoperable, should be taken into consideration.

MULTIPLE-ELEMENT REPLACEABLE FILTERS

The multiple replaceable-element filters used in a central system are simply an extension of the single filter used on a single EDM machine. Filter units used for this type of operation are either high-capacity, single-element, or multiple-element assemblies. Regardless of the style used, a provision must be made that allows the filter to be serviced without removing the EDM machines from service.

EDGE FILTRATION

Edge filtration makes use of numerous cylindrically shaped filter elements contained in a sealed vessel. Each element is an assembly of thin wafers, tightly compressed to restrict the flow of dielectric fluid between them. The wafers are assembled on a tube with openings to allow the flow of dielectric fluid through the tube. As fluid is forced through the passageways between the wafers, EDM chips and sparking debris collect on the outside edges of the wafers.

When debris collects on the wafer edges to the point that dielectric fluid flow is restricted, compressed air is forced through the cylindrical elements in a reverse direction. The debris then separates from the wafer edges, reopening the passageways. The debris flows with the dielectric fluid to the bottom of the vessel and into a collection reservoir. As the dielectric fluid drains from the collection reservoir, the debris becomes a sludge that may be collected and disposed of on a regular maintenance schedule. This type of filter is beneficial because it can be operated automatically and separately from the EDM-machine operation. A second benefit is that filter elements do not have to be kept in inventory. Labor time for filter maintenance is reduced and disposal of the sludge does not include a filter element.

DIATOMACEOUS-EARTH FILTRATION

The diatomaceous-earth-filtration system is made up of flexible tubes in a sealed vessel. Often, the tubes are made of woven wire to form a mesh of many small openings for the passage of dielectric fluid.

Prior to dielectric-fluid filtering, a slurry of diatomaceous-earth tube coating material is added to the fluid. The fluid passes through the woven-wire mesh, while the diatomaceous earth remains on the tube surface and acts as a filter, trapping the EDM debris and then collecting it on the outside of the tubes.

As filtration takes place, the debris builds up, causing a restriction to the flow of dielectric fluid. To return the filter operation to an acceptable level of fluid flow, the woven-wire-mesh tubes are shaken or bounced while fluid is flowing in the system. This bouncing redistributes the diatomaceous-earth coating and collected debris on the flexible tubes and opens passageways for the flow of dielectric fluid. The tubes may be bounced a number of times before needing to be back-flushed to remove the diatomaceous earth and collected debris. Back flushing causes the vessel fluid, diatomaceous earth, and collected debris to flow into a collection reservoir for disposal. After back flushing, the tubes are recoated with diatomaceous earth to start another filtration cycle.

Like edge filtration, operation of the diatomaceous system can be automatic and separate from the EDM-machine operation. It can also include a drying system to remove dielectric fluid from the diatomaceous earth and EDM debris, allowing the material to be disposed of in a semi-dry state.

Ionization and Electrode Wear

9

EDM-electrode wear results from sparking between the electrode and workpiece. In normal EDM operations, material is removed from both the electrode and workpiece. This chapter discusses the various electrode materials used in EDM and how electrode wear occurs.

SPARK OCCURS WITHIN IONIZED COLUMN

While picturing a spark as a small bolt of lightning is acceptable for general discussion, it cannot be used when considering electrode wear. The EDM spark is really a column of electricity flowing through the dielectric fluid between the electrode and workpiece. Figure 9-1 illustrates this concept.

The EDM spark is complex in nature because it involves a number of things that are taking place within a column of electricity. Figure 9-2 illustrates the nature of the electricity as it flows through the column in the dielectric fluid. The actual column of electricity is a plasma. This is a condition where electricity is flowing through a column that has changed from a fluid into a gas. Within this plasma column, electricity flows very easily.

DETERMINING THE SPARKING GAP

The EDM-power supply provides spark electricity. Its open-circuit voltage is applied to the electrode and workpiece while the dielectric fluid fills the space between them. As the electrode advances toward the workpiece, it comes to a point where a spark occurs. This is known as the fluid-ionization point and it is based on the dielectric strength of the fluid and the distance between the electrode and workpiece.

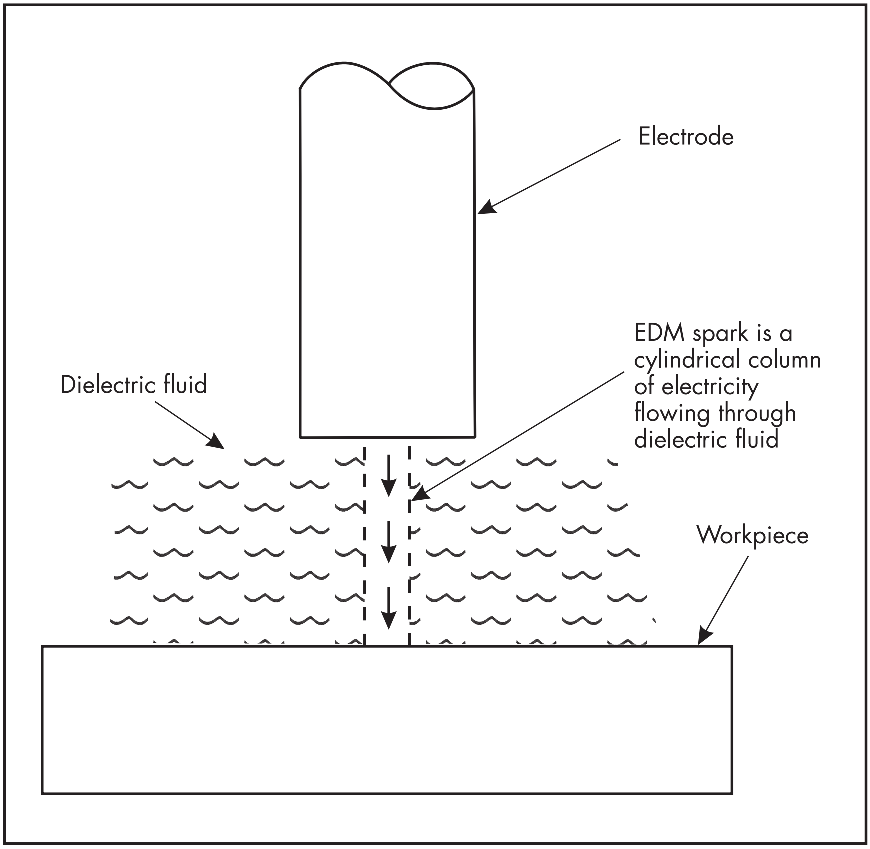


Figure 9-1. The EDM spark is a column of electricity.

The spark is the electricity flowing through the ionized column of dielectric fluid. Within the ionized column, electrons separate from the dielectric-fluid atoms and flow from the negative-polarity electrode toward the positive-polarity workpiece. Since the dielectric-fluid atoms in the column are missing electrons, they are positively charged and flow from the positive-polarity workpiece toward the negative-polarity electrode. These positively charged atoms are known as positive ions. Within the column then, there are electrons flowing in one direction and positive ions flowing in the other direction. This description is based on the electrode being negative and the workpiece being positive. If the polarity is reversed, electrons flow toward the positive electrode and positive ions flow toward the negative workpiece.

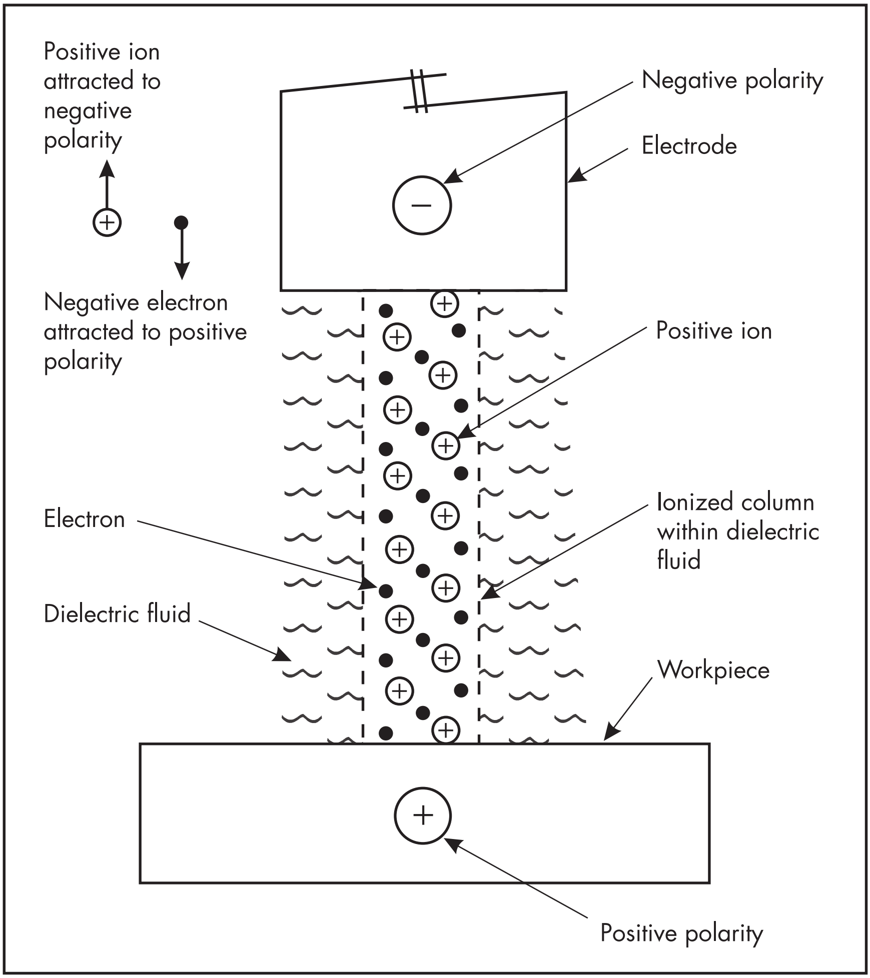


Figure 9-2. The nature of electricity as it flows through the column.

ELECTRODE POLARITY

Electrical polarity of the electrode and workpiece determines the direction of flow for electrons and positive ions. Some EDM manufacturers describe electrode and workpiece polarity as standard and reverse. This description is not acceptable since not all manufacturers use the same polarity for standard and reverse. Because of this, most manufacturers have revised their electrode and workpiece polarity

description to specify only electrode polarity as either negative or positive. It is understood, when using this description, that the workpiece is the opposite polarity of that specified for the electrode.

ELECTRODE WEAR

Electrode wear is a result of either electron or positive-ion bombardment. When the electrode is negative, it is bombarded by positive ions. When the electrode is positive, it is bombarded by electrons. As electrons or positive ions crash into the surface of the electrode, heat is generated. The heat vaporizes the electrode material and a small amount of electrode material is removed with each spark. This removal of material is electrode wear.

Electrode wear is specified in one of four ways, including:

1. corner wear,
2. end wear,
3. side wear, and
4. volumetric wear.

Figure 9-3 illustrates the different kinds of electrode wear.

The number of sparks originating from a point on the electrode surface determines electrode wear. Figure 9-4 illustrates the number of sparks required to produce a flat surface, as compared to the amount required to produce a 90° corner.

Many sparks must originate from the electrode corner to produce the machined shape in the workpiece. By comparison, each spark on the flat surface of the electrode machines a corresponding point on the workpiece. Since each spark removes material from the electrode, more material is removed from the corner than the flat surface, causing electrode wear to be greater on the corner.

CORNER WEAR

Corner wear is the difference between the original electrode length and the point on the electrode corner that still retains the original corner shape. Corner wear is the standard for determining the length of the electrode or the number of electrodes required to complete the workpiece shape in die-sinking operations. There are instances when

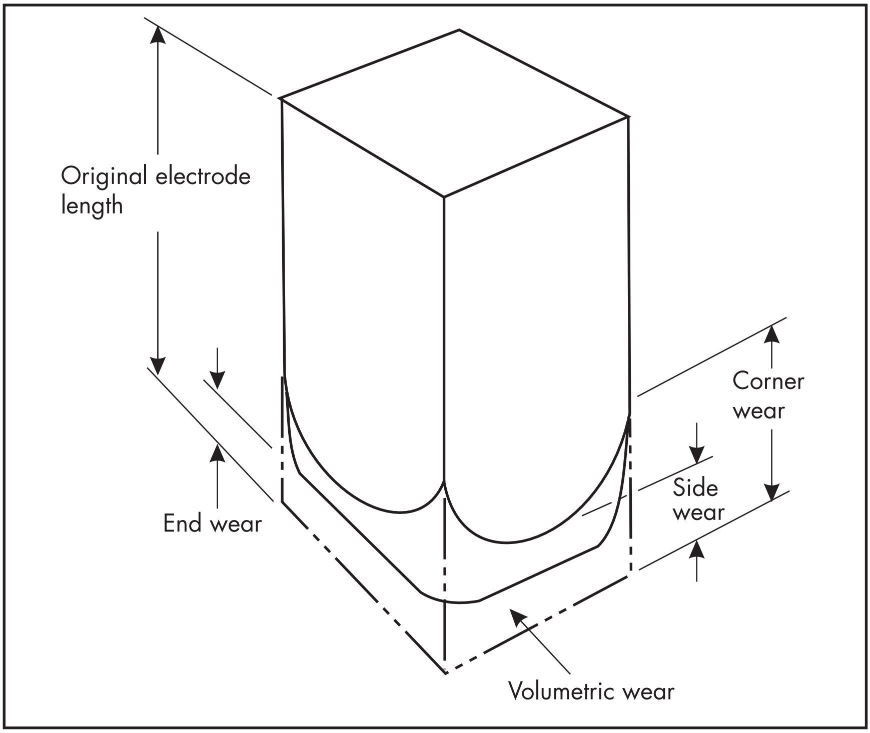


Figure 9-3. The different kinds of electrode wear.

the other types of electrode wear are used as a reference. A brief description of the remaining types of electrode wear follows.

END WEAR

End wear is the difference between the original electrode length and the electrode length after machining. Figure 9-5 illustrates this wear. For the illustration, the workpiece has a hole, pre-drilled before EDM, which is used for dielectric-fluid flow to remove EDM chips. As the electrode machines the workpiece, there are no sparks between the end of the electrode and the workpiece in the area of the pre-drilled hole. The electrode end remains the original length of the electrode. After the EDM operation is completed, the electrode's end wear is noted by measuring the cylindrical extension of the electrode material that has passed through the pre-drilled hole.

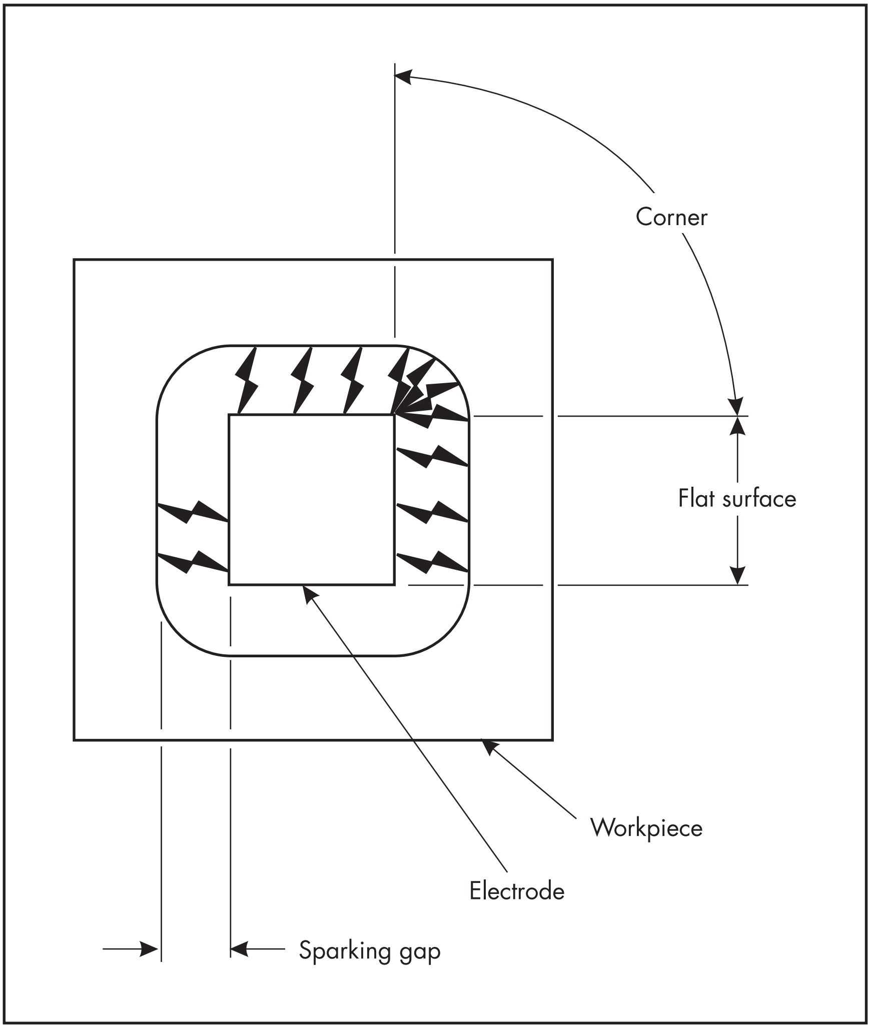


Figure 9-4. Sparks required to produce a 90° corner.

SIDE WEAR

Side wear is the comparison between the original electrode length and the side surface of the electrode that shows the full electrode shape after the machining operation is complete. Side wear is the wear used as a reference on circular electrodes, since corner wear is not a consideration.

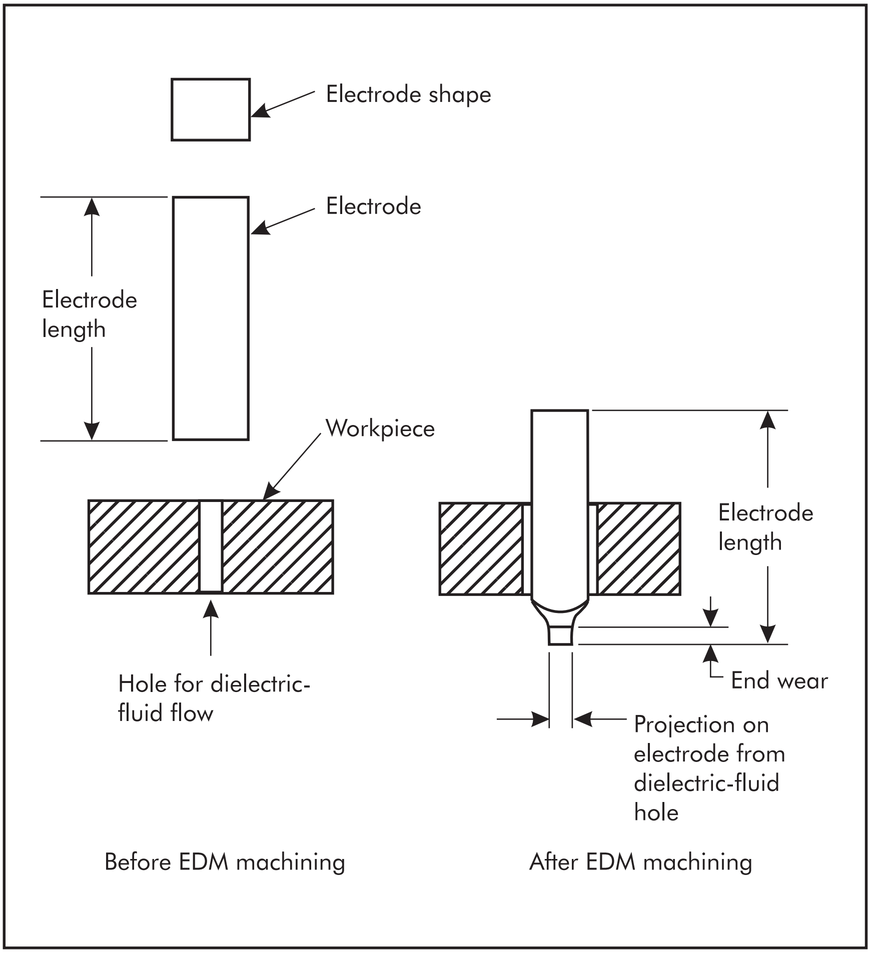


Figure 9-5. Electrode end wear.

VOLUMETRIC WEAR

Volumetric wear is the comparison of the electrode's total volume prior to EDM, to the electrode's volume upon completion of machining. There are instances when this type of wear is used to compare the volume of electrode consumed to the volume of workpiece machined. EDM-research engineers often use volumetric wear for studying and analyzing the EDM process. Seldom is it used for actual EDM operations.

NO-WEAR MACHINING

By using certain electrode and workpiece material, electrode polarity, dielectric flushing, and spark-ON time conditions, electrodes do not appear to wear. This condition is described as "no-wear" machining. No-wear machining requires six things:

1. copper or graphite electrode,
2. steel workpiece,
3. positive electrode polarity,
4. long spark-ON time,
5. low-velocity-dielectric flow through the sparking gap, and
6. no capacitors.

No-wear machining is a process where the workpiece material is impregnated into the electrode material so that it becomes an electrode-sparking surface. In general, no-wear machining applies only to copper and graphite electrodes machining a steel workpiece.

Positive electrode polarity is used in no-wear machining. This means that the workpiece is bombarded by positive ions and that negative electrons bombard the electrode. Figure 9-6 illustrates ion and electron bombardment. Using this polarity removes less workpiece material per ampere than using negative electrode polarity. It also results in increased machining time. Since electrode wear is reduced, fewer electrodes and electrode-redress operations are required.

No-wear machining requires the use of long spark-ON time, which allows the spark column to become larger in diameter and the vaporized workpiece material more time to travel from the workpiece to the electrode surface. The vaporized workpiece material impregnates into the electrode surface and solidifies to become the sparking surface of the electrode. Each spark wears away the impregnated surface, but it is replaced by solidified vapor from following sparks. Figure 9-7 illustrates the spark column and the vapor being transported to the electrode surface during one spark. As the spark is turned OFF, the vapor impregnates into the electrode surface and solidifies to become the sparking surface (see Figure 9-8).

To ensure that the vaporized workpiece material reaches the electrode surface, low-velocity dielectric-fluid flow is provided to the sparking gap. The use of high-velocity dielectric-fluid flow cools most of the

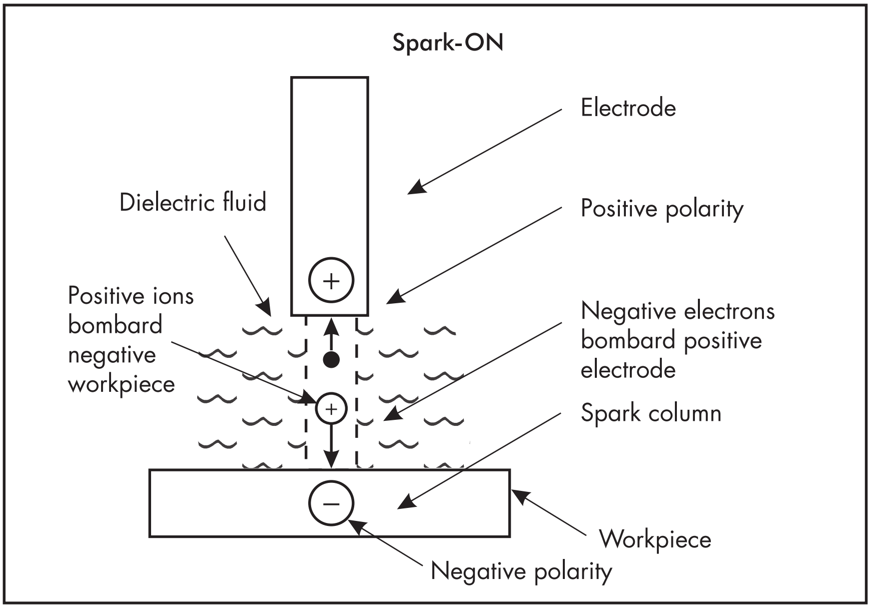


Figure 9-6. Positive ion and electron bombardment.

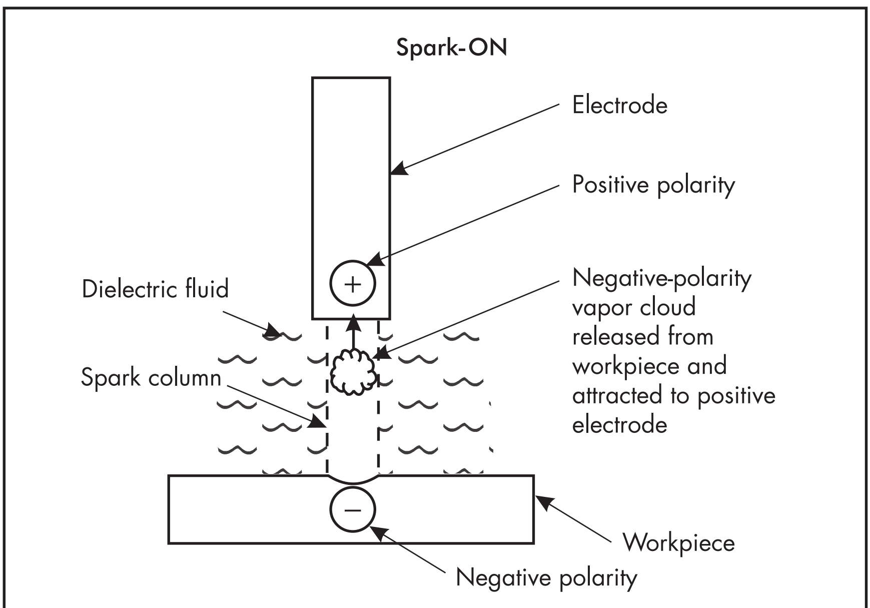


Figure 9-7. Vapor cloud attracted to electrode.

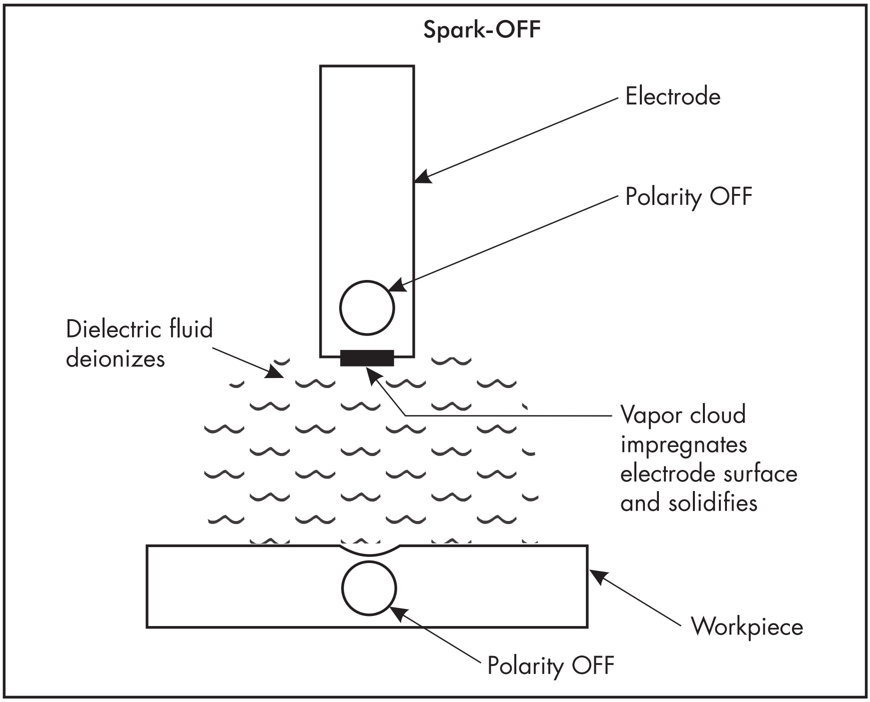


Figure 9-8. Vapor cloud impregnates electrode.

vapor and flushes it out of the sparking gap prior to reaching the electrode surface.

NO-WEAR SURFACE—COPPER AND GRAPHITE ELECTRODES

Electrodes used for no-wear machining have a very distinctive surface appearance after use. Copper electrodes are blackened, while graphite electrodes are silver-gray.

NO-WEAR-SPARK SETTINGS

All EDM manufacturers provide specific recommendations for the settings to be used when no-wear machining is desired. In most instances, capacitor-discharge-power supplies do not produce the required spark characteristics for no-wear machining. Pulse-type-power supplies have a feature important to no-wear-machining operations.

They have the ability to adjust the spark for long ON-time, short OFF-time sparking.

No-wear-machining conditions are produced through the use of long ON-time sparks. A short spark-OFF time is then required to allow the dielectric fluid time to deionize between sparks. Upon deionization of the spark column during the spark-OFF time, the next spark column can ionize at the start of the next spark-ON time. This long spark-ON time and short OFF time results in the use of a long sparking-duty cycle. The spark-OFF time is not a requirement for no-wear machining, but is desirable since this allows the sparks to occur as close together as practical. Short OFF time increases the machining efficiency since more sparks occur in a given amount of time.

No-wear is often beneficial in the machining of three-dimensional cavities. It is possible to use one roughing electrode to produce multiple cavities without redressing the electrode. The no-wear, roughing electrode must be machined to allow for the roughing overcut, so material is available to finish the cavities for final size and surface finish.

It is important to use the exact no-wear settings provided by the machine manufacturer. Deviation from these settings may cause the electrode to grow and distort the electrode's surface form. It is also possible for excessive buildup of the surface to cause pitting or damage to the machined surface of the workpiece and to cause pieces of the electrode surface to break away. Growth of the electrode surface is most noticeable when using graphite electrode material.

No-wear machining is not appropriate for wire-cut machining. The six no-wear-machining considerations previously described do not apply to wire-cut operations.

ELECTRODE MATERIAL

By necessity, electrode materials must be electrically conductive. But, they should also have features such as:

- a high melting point,
- an ability to be easily machined, and
- a low cost.

No single electrode material provides all of the desired features for any particular application. The following list of materials is intended as a guide to electrode materials commonly used for die-sinking machines.

BRASS

Brass is readily available. The grade used is normally specified as free-machining brass. It has a fairly good wear ratio when machining steel, and a very high wear ratio when machining tungsten carbide. Brass is not normally recommended for use with R-C-power supplies.

COPPER

Copper is readily available and normally specified as electrolytic-grade or tellurium-copper alloy. Electrolytic grade may be considered as pure copper. Tellurium copper is copper with the element tellurium added and it is equivalent in machinability to free-machining brass. Copper is difficult to grind but has good no-wear-machining characteristics. It often is used for R-C-power-supply operations.

COPPER TUNGSTEN

Copper tungsten is a sintered material made from copper and tungsten, with a common ratio of 70% tungsten and 30% copper. It has very good wear characteristics. Difficult to machine except by grinding, copper tungsten is often used for machining tungsten carbide.

GRAPHITE

Graphite is available in different densities. The density depends on the grain or particle size (specified in microns) of the powder used to produce the product. Graphite is available in grain sizes ranging from 100 microns for a coarse grade, down to one micron for fine-grade material.

Graphite has very good wear qualities. Although it is very machinable, graphite dust must be considered when machining the material. Graphite does not melt, but rather *sublimes*, meaning it goes from a solid directly into a gas, without melting and going through a liquid state. Graphite's sublimation temperature is approximately equal to the melting temperature of tungsten. Graphite may not be recommended for machining tungsten carbide.

A fine-grain size is recommended for fine-detail machining. Graphite has very good no-wear-machining characteristics and very good machinability by cutting tools or grinding. It may not be recommended for use with R-C-power-supply operations.

COPPER GRAPHITE

Copper graphite is fine-grain graphite that is infiltrated with copper. It has the qualities of graphite, plus the electrical conductivity of copper.

ZINC ALLOYS

Zinc alloys may be used as an electrode material, but the wear characteristics are very poor.

CARBON

Carbon may appear to be very much like graphite. However, it is a much different material and is unacceptable as an EDM electrode.

ELECTRODE CORNER-WEAR COMPARISON

Table 9-1 lists the approximate 90°-corner wear that may be expected when using certain electrode polarities in different combinations of electrode and workpiece materials. The electrode wear listed is based on a workpiece-material thickness of 1 in. (25 mm).

The electrode must pass through the workpiece in such a way that the corner wear shows the original form without wear. The electrode length must take into consideration the workpiece thickness, as well as the thickness to attach the electrode to a holding device. In many instances, this requires using considerably more electrode material than is needed for the machining operation. Figure 9-9 illustrates the corner wear and the electrode material required for the workpiece thickness and electrode holding.

Table 9-1. Approximate electrode wear for 90° corner

Electrode	Workpiece	Polarity	Wear in. (mm)
Brass	Steel	Negative	1.50 (38.100)
Brass	Tungsten carbide	Negative	4.00 (101.600)
Copper	Steel	Positive	0.10 (2.540)
Copper	Steel	Negative	1.00 (25.400)
Copper	Tungsten carbide	Negative	0.60 (15.240)
Copper tungsten	Steel	Positive	0.40 (10.160)
Copper tungsten	Tungsten carbide	Negative	0.70 (17.780)
Graphite	Steel	Positive	0.01 (0.254)
Graphite	Steel	Negative	0.40 (10.160)

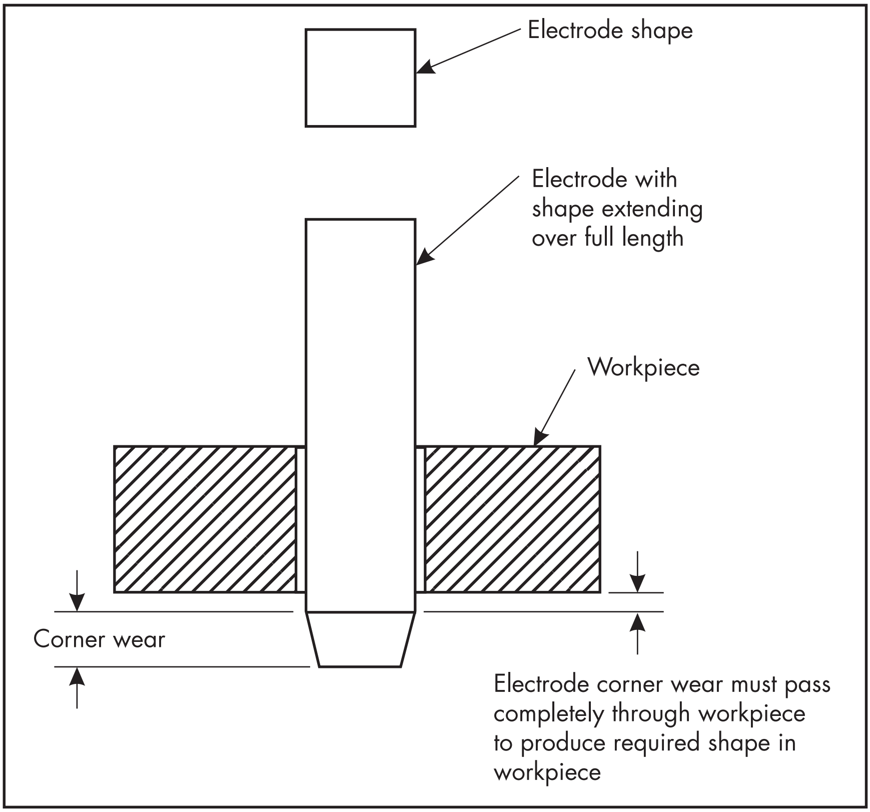


Figure 9-9. Electrode with shape extending over full length.

Figure 9-10 shows an electrode design using a shank for passing the electrode through the workpiece thickness with additional length for holding the electrode. Using the shank design substantially reduces the amount of electrode material compared to using a full-form electrode.

WIRE-CUT-EDM ELECTRODES

As the wire-cut description indicates, electrodes for wire-cut machines are always round wire, purchased on a spool or reel. There is no need to consider how the electrode will be machined. Only one-half of the electrode diameter is subject to wear as the wire passes

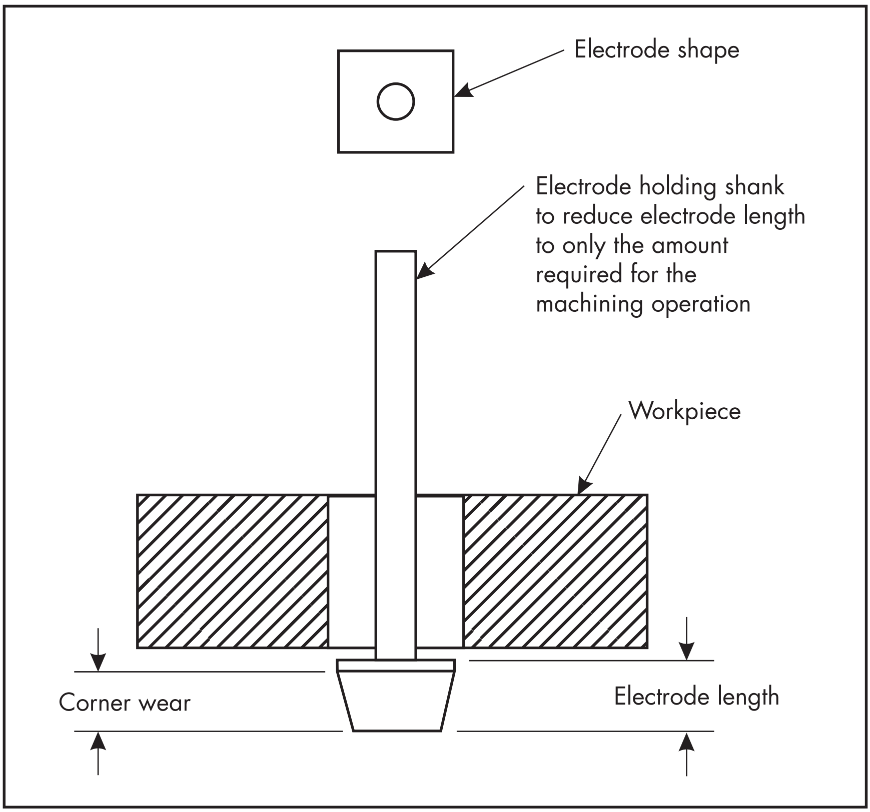


Figure 9-10. Using holding shank to reduce electrode length.

through the sparking area. Figure 9-11 illustrates the wire-cut-wear pattern on the electrode wire.

It may appear that the wire-wear pattern would allow the electrode wire to be reused. But re-using the electrode reduces the tensile strength and could result in breakage when the required tension is applied for the machining operation during reuse. The normal practice is to dispose of the electrode wire after it makes one pass through the sparking area.

Wire-cut wire suppliers normally provide the electrode material in sealed packages to prevent deterioration of the surface by oxidation. Surface oxidation reduces the electrical conductivity of the wire at the point when sparking electricity is applied from the power supply. This detrimentally affects the machining operation. It is recommended that any spool or reel removed from the machine for future use be repackaged and sealed to prevent further oxidation of the electrode surface. Most wire-cut machines use electrode wire in a diameter range of .004–.014 in (0.1–0.35 mm).

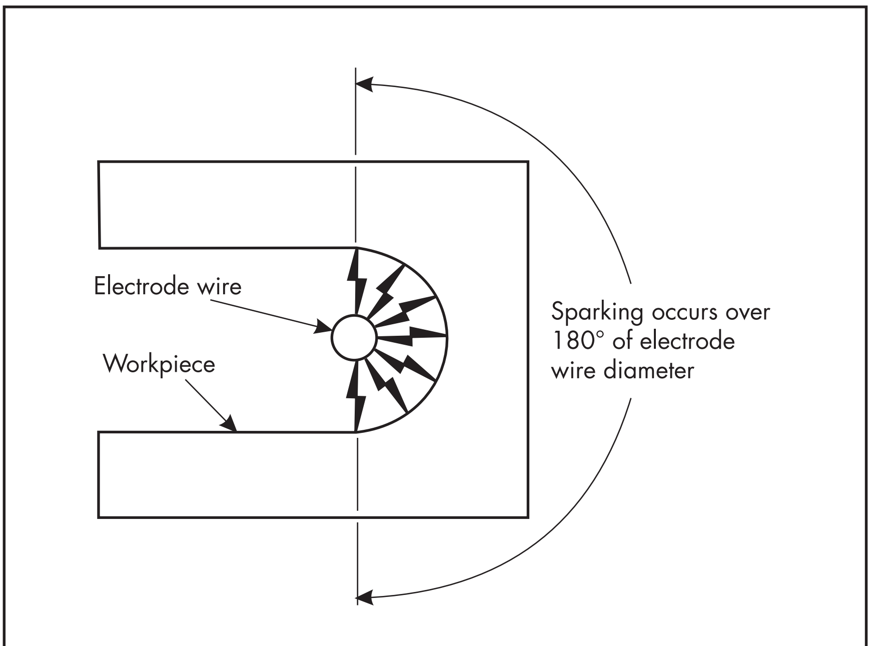


Figure 9-11. Wire-cut electrode wear.

COPPER WIRE

The first wire-cut electrode material used was copper wire because it was readily available in precision-drawn sizes and because it had good electrical conductivity. But copper wire did not have the strength needed to keep it straight when tension was applied. For this reason, other materials were examined for their mechanical and electrical characteristics.

BRASS WIRE

Brass became the electrode material of choice as wire-cut machines were developed. Brass is copper, alloyed with zinc. The copper and brass alloy may be formulated to produce the required tensile strength, while maintaining good electrical conductivity. Brass also is available in different hardnesses, described as soft, 1/2 hard, and hard. The hardness used depends on the machining operation to be performed. As hardness increases, the wire becomes more resistant to a change in direction as it passes through the machine's wire guides.

Soft brass is used if the electrode wire must traverse through the machine's wire guides to produce an angled surface in the workpiece. The softness of the material allows the wire to readily change direction as it traverses through the wire guides. This feature is beneficial when machining angles of 7° and greater. It may be possible to machine angles of less than 7° with harder brass alloys.

Brass wire, when described as 1/2 hard and hard, has a "memory." The wire memory resists any change from the curvature that it has as it is unreeled from the spool—not a desirable feature when considering steep-angle machining. Brass wire lends itself to the more-perpendicular-wall machining. The harder alloys tend to feed through the machine's automatic re-threading mechanisms more readily than the soft brass.

ZINC-COATED WIRE

Zinc is used as a coating for wire-cut electrode wire. The zinc provides good electrical conductivity over a core-wire material with good tensile strength. The zinc also forms a protective heat-shield barrier

between the electrode core and the heat generated by the spark. Figures 9-12 and 9-13 illustrate the use of the heat-shield barrier.

Figure 9-12 illustrates the double-boiler principle. This technique is used to cook food when the temperature of the food cannot exceed the boiling temperature of water—212° F (100° C). Heated by flame, the water is boiled in the lower vessel. The boiling water's 212° F (100° C) temperature is transmitted to the upper vessel through the steam it produces. This keeps the food in the upper vessel from being heated above the temperature of the boiling water.

Figure 9-13 illustrates the double-boiler principle for wire-cut electrode wire with a zinc coating. The zinc coating on the wire core boils as the electrode wire is bombarded during the spark. As the coating boils, it vaporizes at a temperature lower than the melting temperature of the wire-core material. This zinc vapor accepts heat from the spark that would be transmitted directly to the wire-core material if the zinc-vapor barrier were not present. By accepting this heat, the zinc-vapor barrier reduces the amount of heat transmitted to the electrode core and the amount of wear on the electrode surface.

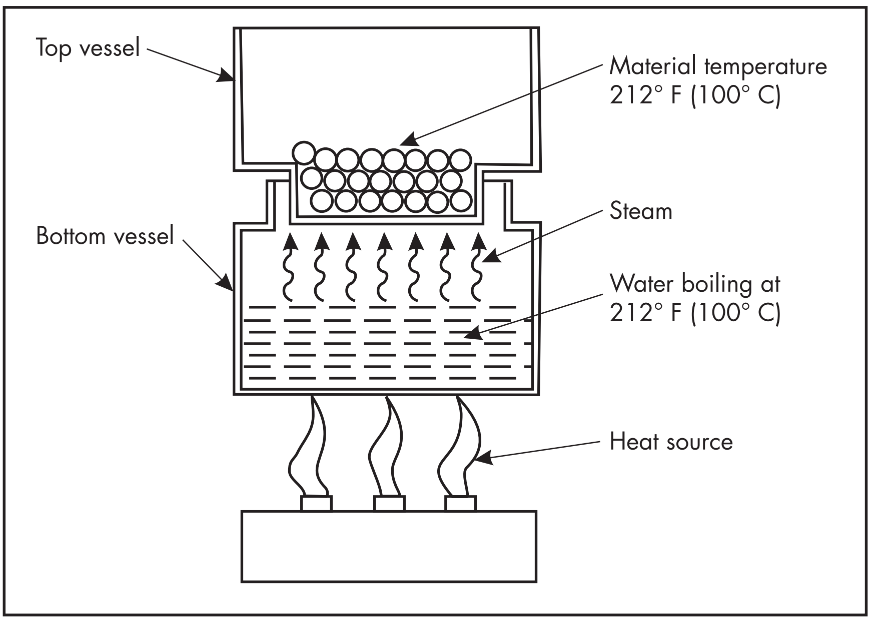


Figure 9-12. Double-boiler principle.

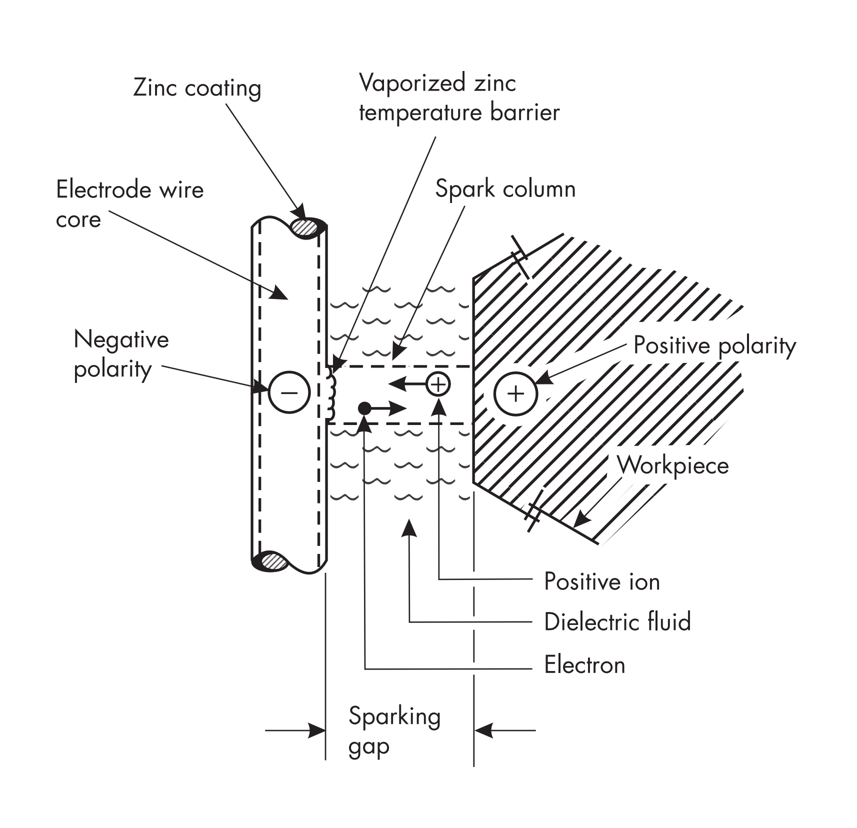


Figure 9-13. Vaporized zinc reduces electrode temperature.

DATA FOR WIRE SELECTION

Wire-cut-machine manufacturers provide a computer database, listing optimal machine settings for machining operations. These settings are based on items such as workpiece material and height. Using this information, the electrode-wire material and diameter are specified and input into the computer for the recommended wire tension and wire-feed speed settings. The EDM machinist has the option to input data other than at the settings provided by the computer, based on experience. During the machining operation, the machinist may also modify settings to suit the specific needs of the machining operation.

SUMMARY

All EDM-machine manufacturers provide detailed information about recommended electrode material, electrode wear, and electrode polarity. It is important that the machine user make use of manufacturer-provided training schools and application assistance for a high level of machine proficiency.

Electrode-material suppliers also provide important assistance in the selection and use of their products.

EDM Chips

10

Electrical Discharge Machining is a process where chips are produced by the thermal energy that results from the bombardment of the workpiece and electrode by positive ions and electrons. Figure 10-1 illustrates chip production from surface bombardment.

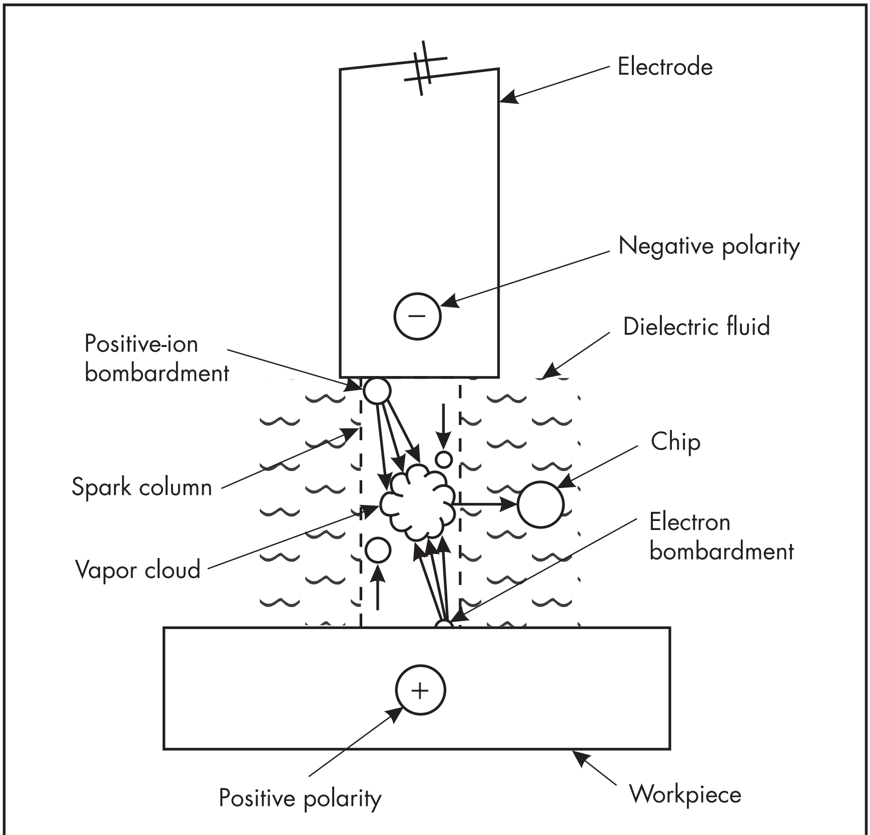


Figure 10-1. EDM chip formation.

CHIP FORMATION

With negative electrode polarity, positive ions are attracted to the electrode surface. Ions crash onto this surface with enough force to generate a heat that vaporizes the surface. Simultaneously, electrons are so forcefully attracted to the positive workpiece that the resulting heat also vaporizes that surface. Vapors from the electrode and workpiece surfaces then combine. Cooling from the outside in, the combined vapor solidifies as a hollow sphere-shaped chip in the dielectric fluid. The EDM chips then contain material from both the electrode and workpiece.

When a positive electrode polarity is used, an electrode is bombarded by electrons and the negative workpiece is bombarded by positive ions. Each spark produces a chip and sparks occur within a normal frequency range of 2,000–500,000 sparks per second. The chips are very small—their size is measured in millionths of a meter (micron). But, if chips are not removed at the same rate they are produced, they will collect in the sparking gap and detrimentally affect the sparking process. Figure 10-2 illustrates the consequence of allowing chips to collect in the sparking gap.

RESULTS OF CHIPS REMAINING IN SPARKING GAP

If chips are not removed from the sparking gap, the spark electricity is forced to pass through the chips on the workpiece surface. As it does so, the electricity re-machines the chips into smaller ones, which requires spark energy and reduces the size of chips being removed from the workpiece surface. This smaller than normal amount of workpiece material being removed creates inefficient EDM operations.

Collection of chips in the sparking gap produces another condition that further reduces machining efficiency. Because chips are free to move about the workpiece surface, variances are caused in the electrode-to-workpiece voltage that cause unstable servo operations. The machine's servo system advances and holds position or retracts the electrode from the workpiece by comparing the electrode-to-workpiece voltage to a reference voltage. The movement of the chips on the surface is increased as the electrode moves forward and reverses. Chips

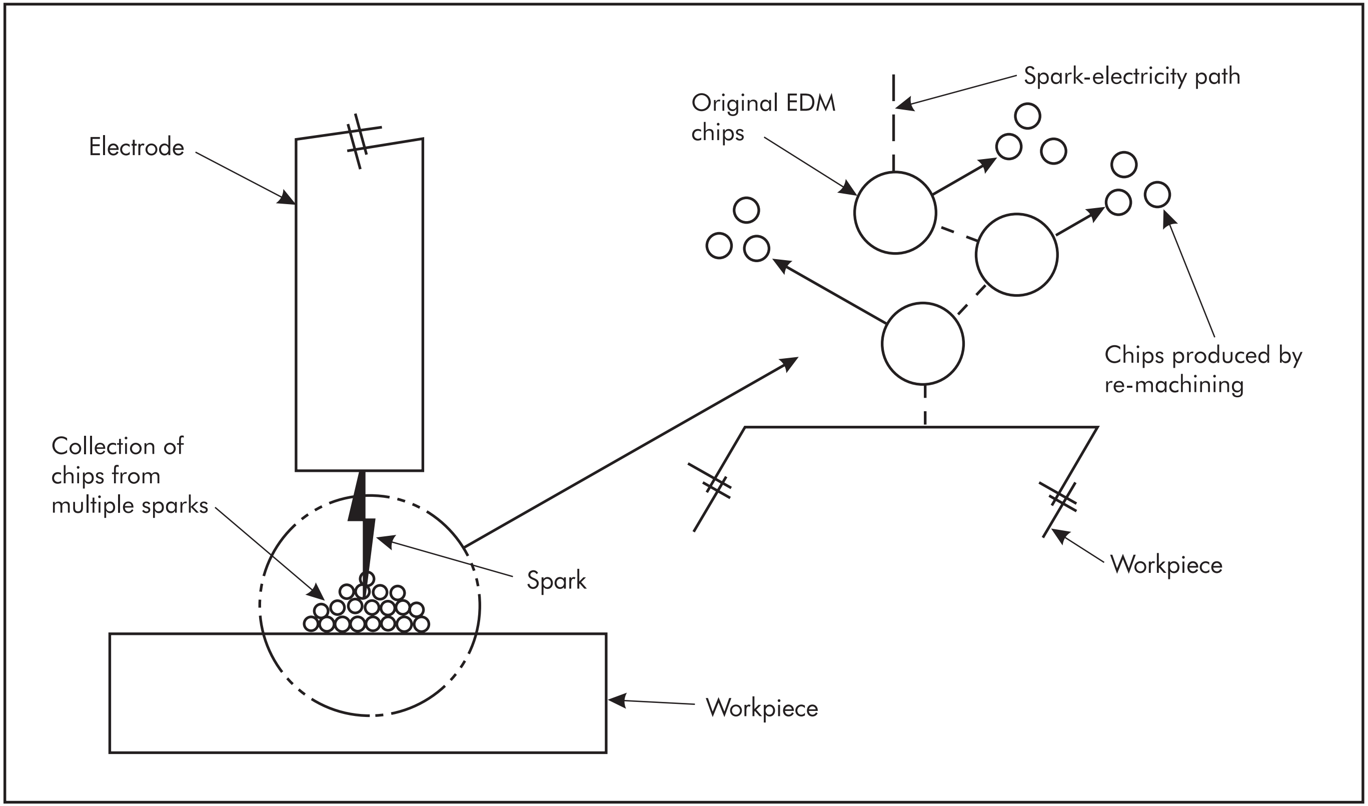


Figure 10-2. Chip collection and re-machining in sparking gap.

also move as the dielectric fluid flows in and out of the sparking area. Since the servo system attempts to react to the electrode-to-workpiece voltage and this voltage varies with the chip movement, unstable servo operation results.

USING DIELECTRIC FLUID FOR CHIP REMOVAL

EDM manufacturers include the capability of flowing dielectric fluid through the sparking gap as part of the machine's dielectric system. The machine user must connect the electrode, workpiece, and tooling to the machine's dielectric system in a way that provides proper fluid flow for efficient chip-removal operations.

FLUID-FLOW PATHS

In reviewing fluid flow for chip removal, it is important to note that fluid always flows by the shortest escape path. Figure 10-3 illustrates the fluid-flow paths of round, square, and rectangular shapes.

A round electrode with a center hole is the ideal shape for fluid flow and chip removal. The outside diameter is equidistant at all points from the center hole so dielectric fluid covers the entire electrode-end surface as it exits the sparking area.

A square electrode shape restricts the fluid flow in corner areas since corner flow paths are longer than those from the fluid hole to the center point of the flat-side surfaces. The fluid-flow-restricted areas are observable on the workpiece's machined surface as blackened areas. Those areas where fluid is flowing will be clean. Increasing fluid flow does not change the exiting flow path and the higher velocity may cause erosion to the electrode surface.

Dielectric flow through multiple holes along the centerline of a rectangular-shaped electrode involves similar problems. Assuming these dielectric-flow holes are spaced at twice the distance of the dimension from the horizontal centerline to the workpiece outside edge, the fluid at the horizontal centerline will be restricted between the holes. The end holes have the same flow restriction as the square electrode shape.

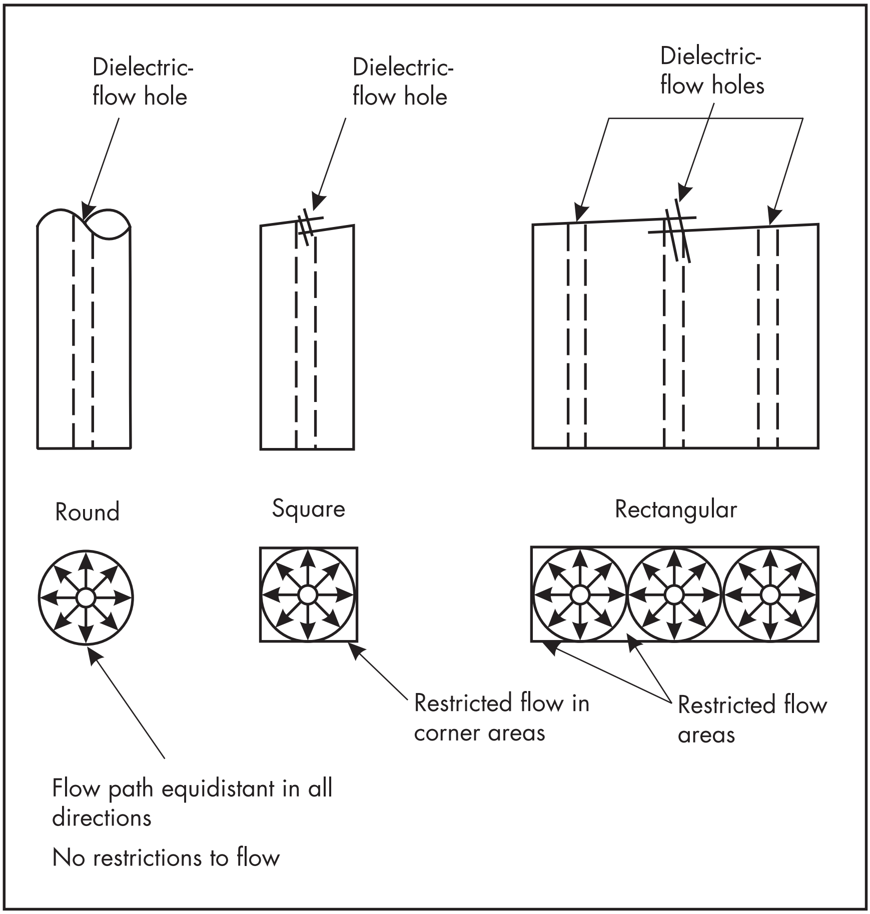


Figure 10-3. Comparison of dielectric-fluid flow paths.

TYPES OF DIELECTRIC FLOW FOR CHIP REMOVAL

In general, die-sinker machines provide for dielectric-flow removal of chips in one of the following ways:

- pressure flow,
- vacuum flow,
- external flow, or
- mechanical motion of the electrode.

PRESSURE FLOW

Pressure flow uses any means of creating a positive fluid pressure to make the dielectric fluid flow through the sparking gap. When conditions permit, it is the chip removal means of choice. Figure 10-4 illustrates pressure flow through the electrode and workpiece.

Using pressure flow, the dielectric-flow path through the sparking gap appears to be the same for both the electrode and workpiece. But before making a final decision on the best means of flow, other things, such as loss of fluid at the electrode break-through point and the amount of standing projection remaining in a three-dimensional cavity, need to be considered.

ELECTRODE-PRESSURE FLOW

Figure 10-5 illustrates fluid flow through the electrode.

Using a dielectric-flow hole in the electrode leaves a core of the workpiece material extending into the hole. Pressurized fluid must then flow past this core and continue past the electrode's outside surface, before exiting into the dielectric fluid contained in the machine's work tank. This fluid flow is restricted by the size of the sparking gap and the depth of the shape machined into the workpiece. As the electrode progresses into the workpiece, fluid pressure must be adjusted to compensate for the additional length of travel required for fluid to exit into the work tank and maintain efficient chip-removal conditions.

Figure 10-6 shows how pressure flow affects the electrode when it machines through the workpiece.

There is end wear on the electrode as it progresses through the workpiece. Although the wear might be expected to be uniform across the end surface, it usually is not, since a portion of the electrode end machines through the workpiece, while other portions are still sparking from the electrode end. The portion that machines through creates an opening for the dielectric fluid to escape. This changes the flow pattern of the fluid through the sparking gap and causes chips to collect in other sparking areas, thus producing erratic servo action.

There are some tooling procedures that improve servo-action efficiency at the time of electrode break-through. For example, using a rotating spindle to turn the electrode creates equalized wear on the

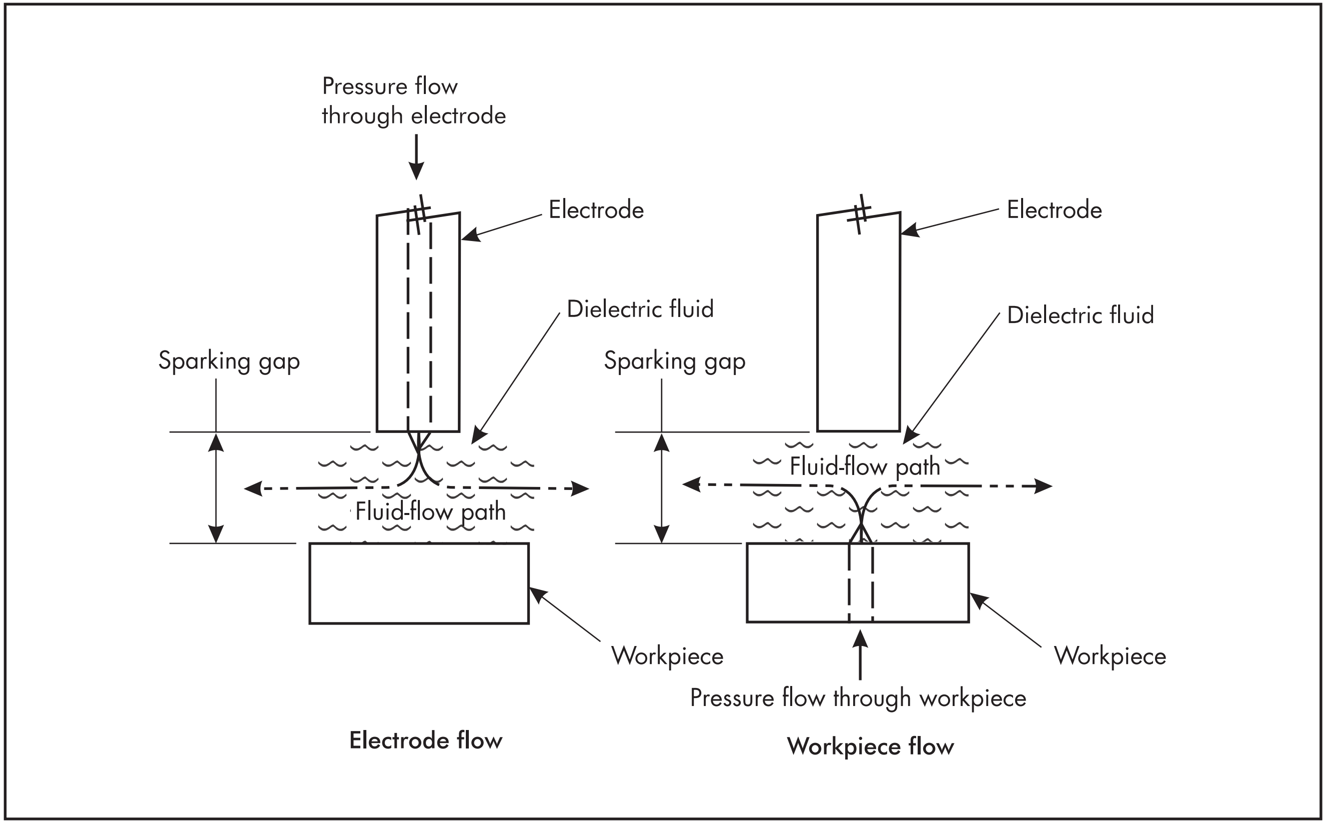


Figure 10-4. Pressure flow through the electrode and workpiece.

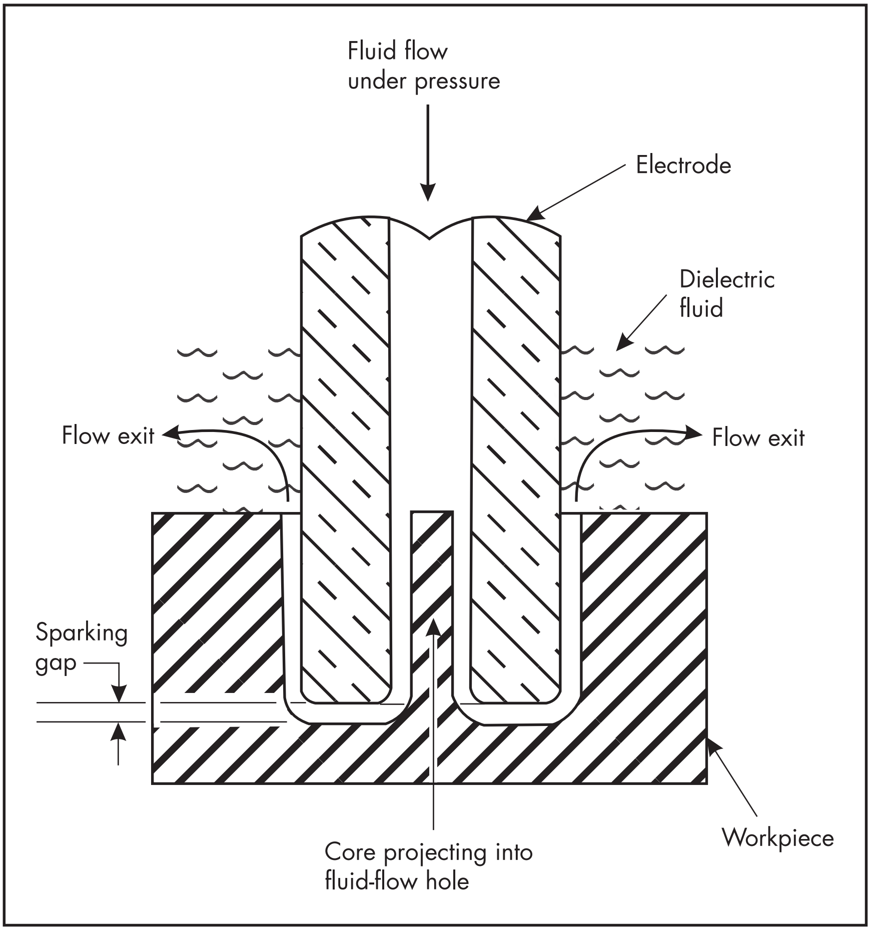


Figure 10-5. Fluid-pressure flow through electrode.

electrode end so that it stays flat and breaks through the workpiece end simultaneously.

Using a backing plate at the break-through side of the workpiece is another tooling technique. Here, the electrode will continue sparking into the backing plate as it completes the machining of the workpiece.

The standing core that projects into the electrode's fluid-flow hole also needs to be taken into consideration. At the time of electrode break-through, the core is released from the workpiece material and this will cause the electrode to retract. Figure 10-7 illustrates this condition.

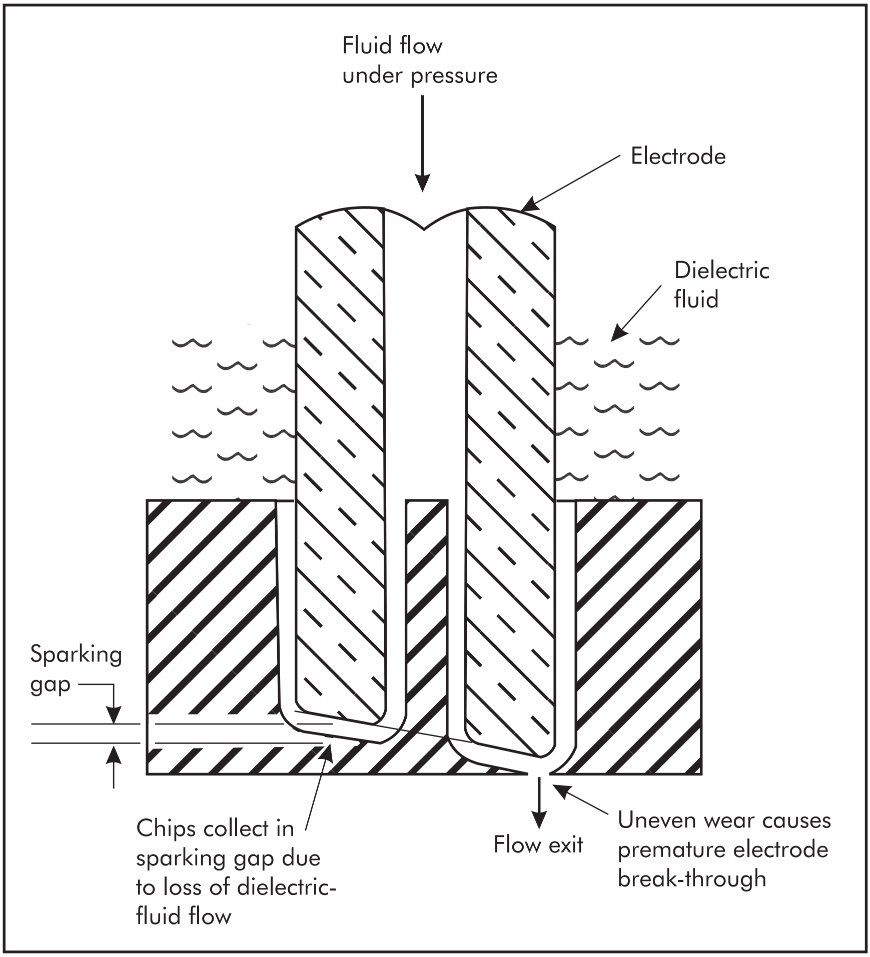


Figure 10-6. Loss of dielectric flow at break-through.

The servo retracts because the core of the fluid hole tilts sideways when it is released from the workpiece material and makes contact with the inside of the electrode's fluid hole. This causes an electrical short between the electrode and workpiece and stops all sparking since there is no sparking gap. The servo system recognizes this low electrode-to-workpiece voltage and commands the servo to retract the electrode from the workpiece. Electrode retraction continues until the electrode is clear of the tilted core and open-circuit voltage is detected. When detected, the servo advances the electrode toward the workpiece until

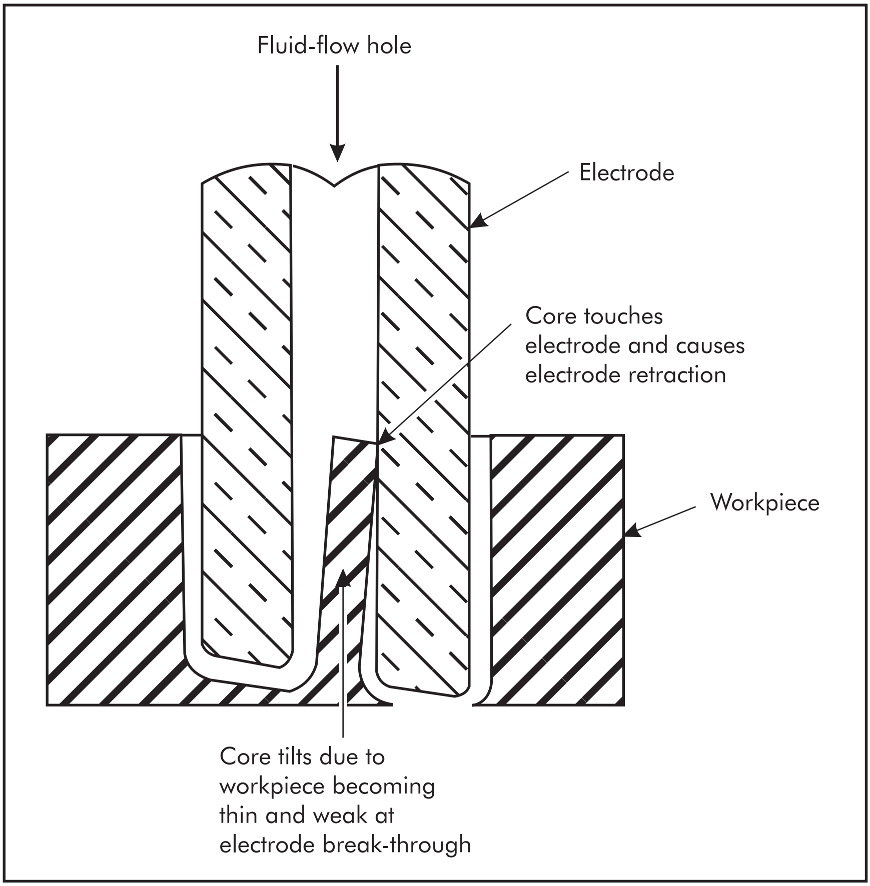


Figure 10-7. Fluid-hole core causes electrode retraction.

sparking occurs. In this instance, the sparking is between the electrode and core and it continues there as long as there is an electrical connection between the two. But since the core has separated from the workpiece material, the electrical connection between the two may be poor or non-existent. The servo system will then be unable to detect a voltage change when the electrode approaches the core and will drive the electrode into the core, possibly with enough force to cause substantial mechanical damage.

Whenever machining is to be accomplished completely through the workpiece, wire-cut machining—if available—should be the method of first choice.

WORKPIECE PRESSURE FLOW

When the dielectric fluid flows through the workpiece for chip removal, there are advantages over electrode pressure flow. A primary advantage is that it does not produce a workpiece core that projects into the electrode's fluid-flow hole. Figure 10-8 illustrates this method of chip removal.

Dielectric-fluid flow through the workpiece often makes use of holes required for other purposes, such as the core-pin and ejector-pin holes used to remove parts in three-dimensional cavities. Fluid flow through the workpiece does require a fluid-flow manifold in the workpiece setup tooling. When using a manifold for dielectric-fluid flow, the mounting surfaces between the workpiece and manifold must match to prevent the escape of pressurized fluid. If leakage occurs,

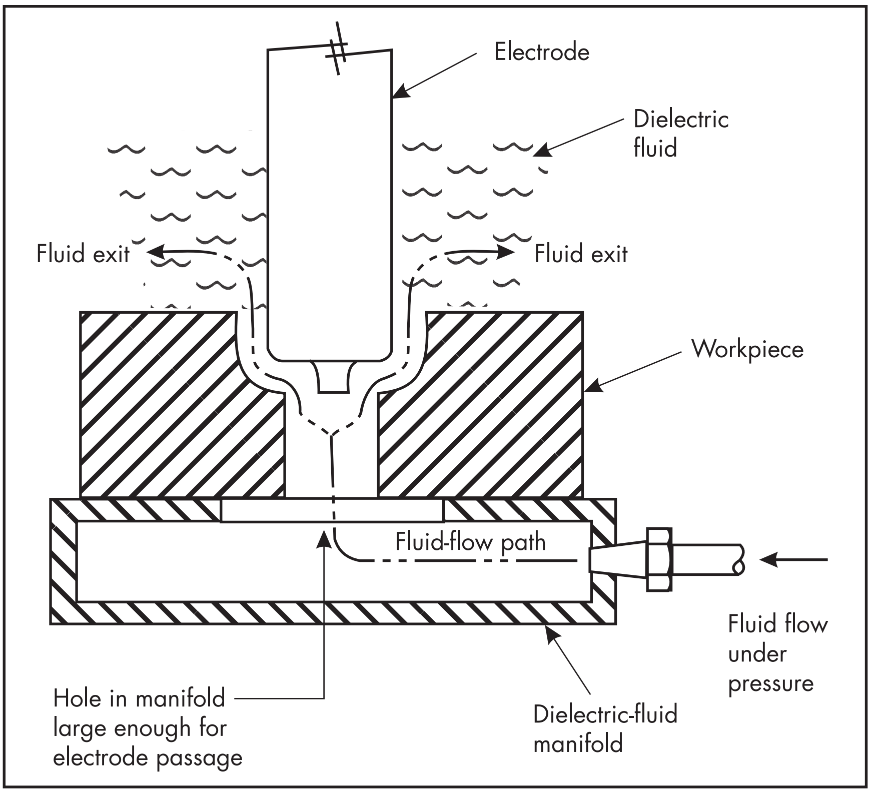


Figure 10-8. Workpiece pressure flow for chip removal.

fluid flow through the sparking gap will be reduced; chips and sparking debris will collect in the sparking area; and servo action will be erratic. This debris buildup could also cause a DC-arcing condition.

Providing fluid flow through holes in the workpiece removes workpiece material prior to the EDM operation. This reduces the amount of material removal and shortens the machining time.

By having the hole in the dielectric manifold larger than the electrode, it is possible for the electrode to pass completely through the workpiece with positive pressure and good chip-removal conditions. The servo action should then remain stable throughout the complete machining operation. It is possible, however, for some erratic servo action to occur at the point of electrode break-through because of the workpiece becoming very thin as it is machined. Pieces of this thin material may break away or flex and contact the electrode. If erratic servo action is noted, it is advisable to stop the machining cycle, remove the weakened material, and then return to the machining operation.

THREE-DIMENSIONAL-CAVITY FLUID FLOW

When machining three-dimensional-cavity shapes, chip-removal fluid should flow through existing holes in the workpiece. This procedure works best when all surfaces begin sparking at the same time. If some projections spark before others, it may be preferable to direct the fluid flow through the electrode. Figure 10-9 illustrates this condition.

It is best to flow fluid through the electrode because the electrode holes can be tapped and inserted with set screws to plug them until the particular projection is about to spark. The set screws are removed just prior to sparking and positive fluid flow is maintained.

Erratic servo action will occur if set screws are used to plug fluid-flow holes and if a set screw is not removed prior to sparking at that particular location. There are two reasons for this: 1) fluid flow is restricted and 2) the set screws become part of the electrode-sparking surface. Set screws are normally made of steel. Thus, a steel electrode machining a steel workpiece normally causes erratic servo action. It is good machining practice to set the machining depth-stop device at a point just prior to the start of the next projection sparking point. This procedure serves as a reminder that a set screw must be removed before continuing the machining operation.

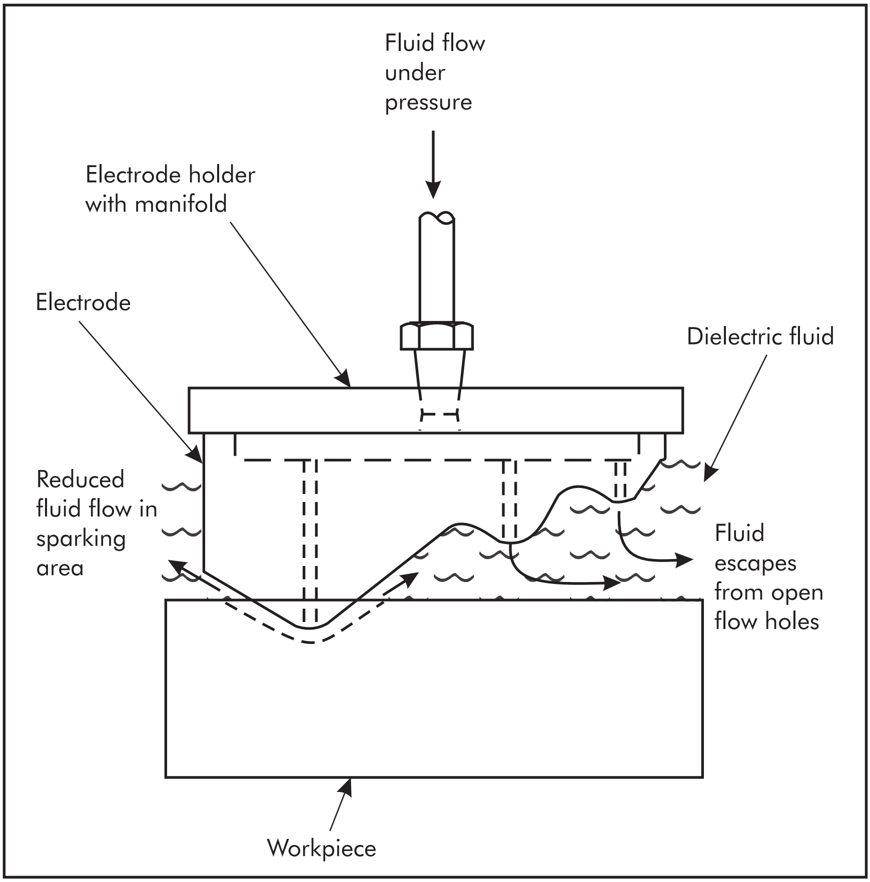


Figure 10-9. Irregular projections reduce fluid flow to sparking area.

Using electrode fluid-flow holes also produces standing core projections in the machined cavity, which are removed by mechanical means. It is possible to reduce the height of these projections by drilling the electrode fluid-flow holes at an angle to the electrode's advance direction. Sparking occurs between the fluid-flow-hole surface and the top of the projection as the electrode advances. Figure 10-10 illustrates this method of reducing the core-projection height.

While angled holes reduce the core-projection height, they do not eliminate the projection. The remaining amount of projection must still be removed to complete the cavity. Because of this, it may be best to drill the fluid holes in line with the direction of electrode travel and

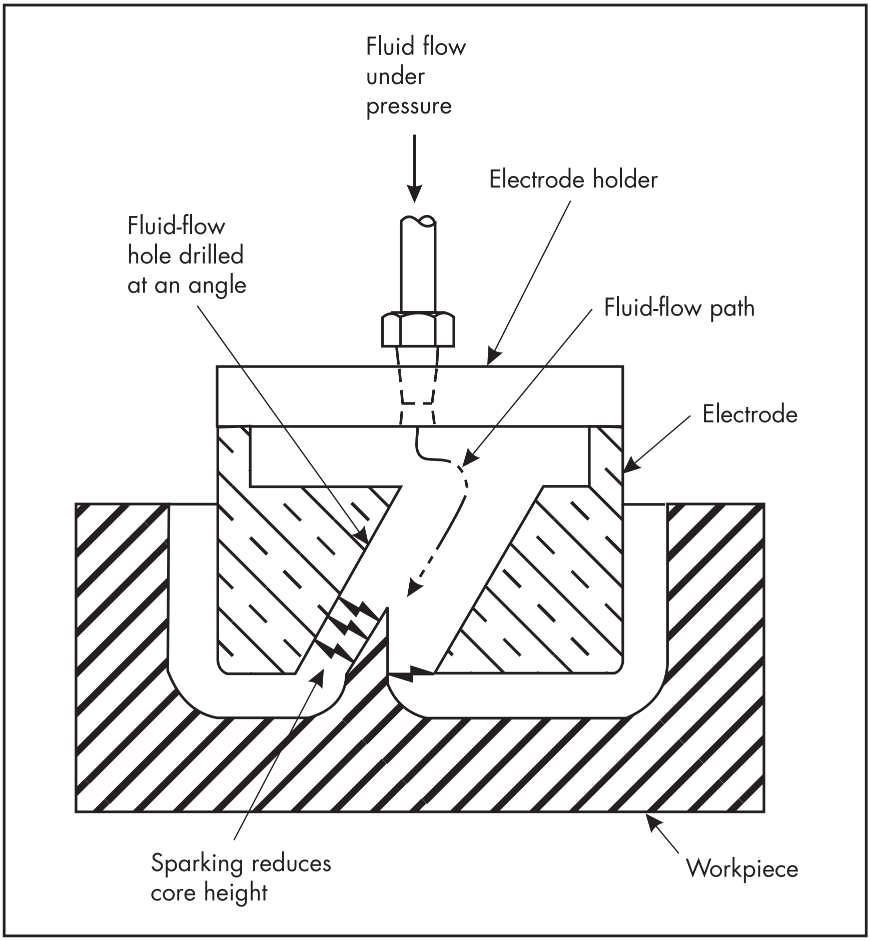


Figure 10-10. Angled fluid-flow holes reduce core projection height.

then perform the removal of the projection after the machining operation is complete.

Smoke and Gas Collection

Caution must be exercised when using electrode shapes that can collect the smoke and gas by-products of the dielectric breakdown during sparking. Figure 10-11 illustrates such an electrode shape.

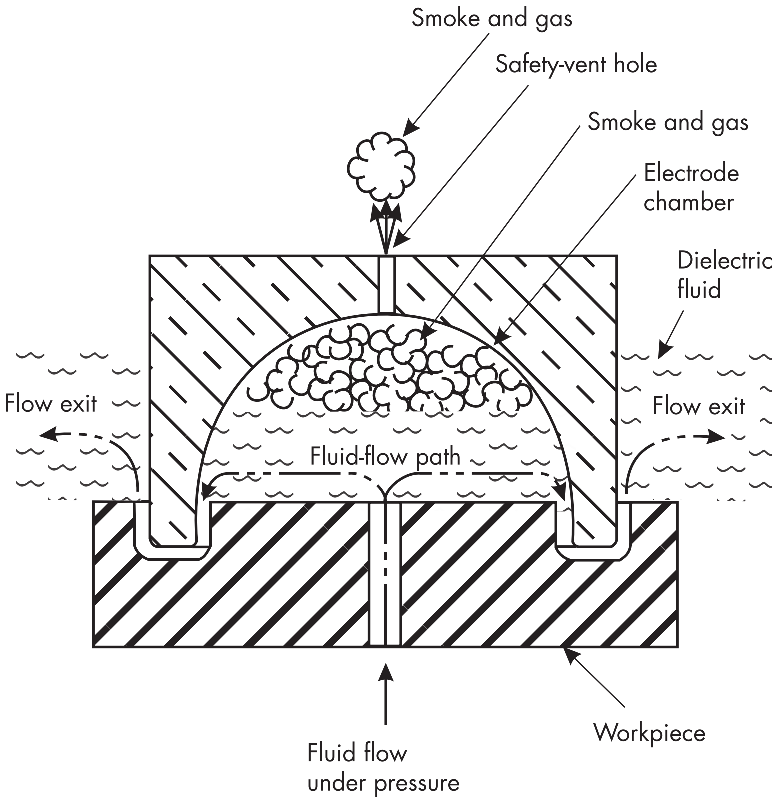


Figure 10-11. Collection of smoke and gas inside electrode.

Hydrogen Gas: Collection and Possible Ignition

As the electrode approaches the workpiece, fluid flows into the electrode chamber and traps air at the top. This prevents the chamber from being completely filled by dielectric fluid. As EDM sparking proceeds, smoke and gas from the fluid break down and displace the air. The smoke contains hydrogen that, if ignited by sparking, could explode the electrode and cause injury.

To prevent collection of smoke and gas, the electrode chamber must be vented by drilling an escape hole at its high point.

VACUUM FLOW

Vacuum flow offers a way to reduce sparking between the electrode and the workpiece sidewalls. Side sparking causes the workpiece sidewalls to be tapered, rather than perpendicular, when using straight-sided electrodes. When pressure-fluid flow is used, EDM chips are transported from the end-sparking area up and past the electrode sidewalls. Figure 10-12 illustrates this.

SIDE SPARKING AND SIDEWALL TAPER

Filtered fluid is introduced into the sparking gap between the electrode end and the workpiece. Chips are generated as the electrode proceeds into the workpiece. As the chips are transported with the

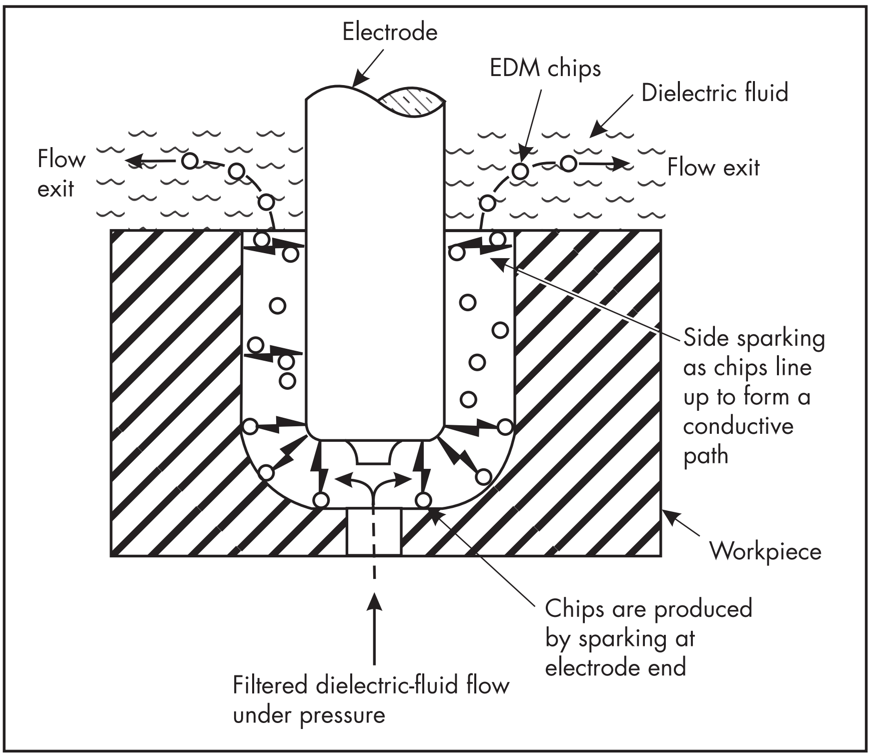


Figure 10-12. Chip removal by pressure-fluid flow.

fluid past the sidewalls, they will occasionally line up between the electrode and workpiece. When the spacing of the line-up is close enough for the chips to ionize the dielectric fluid, a spark will occur between the electrode and workpiece. This occasional sparking removes material from the workpiece surface. The point at which the electrode enters the workpiece is exposed to the possibility of occasional sparking for the greatest amount of machining time. Therefore, more workpiece material is removed by the occasional sparking at the electrode's entry point than at the bottom of the workpiece sidewall. Figure 10-13 illustrates side sparking and the taper it produces on the workpiece wall.

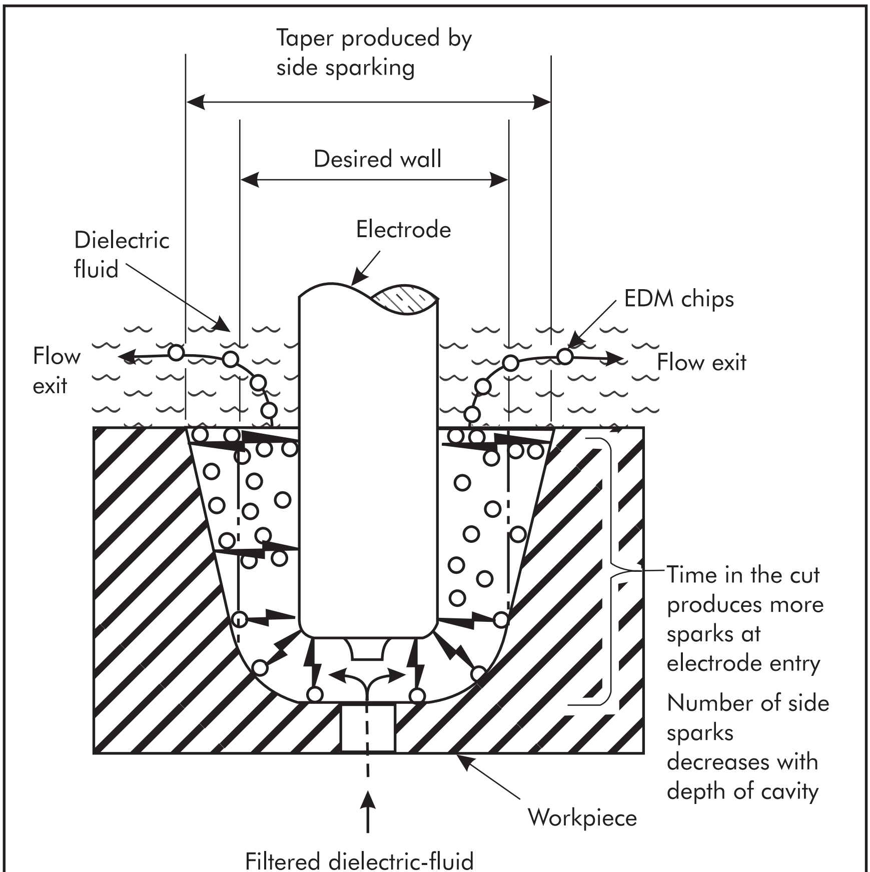


Figure 10-13. Taper produced by sidewall sparking.

To produce sidewalls without taper, sidewall sparking must be eliminated. Vacuum-fluid flow allows the chips to exit the sparking gap without passing the electrode sidewalls. Figure 10-14 illustrates chip removal by vacuum flow.

VACUUM FLOW FOR REDUCTION OF SIDEWALL TAPER

Figure 10-14 shows chips exiting the sparking gap through the workpiece, rather than passing between the electrode and workpiece

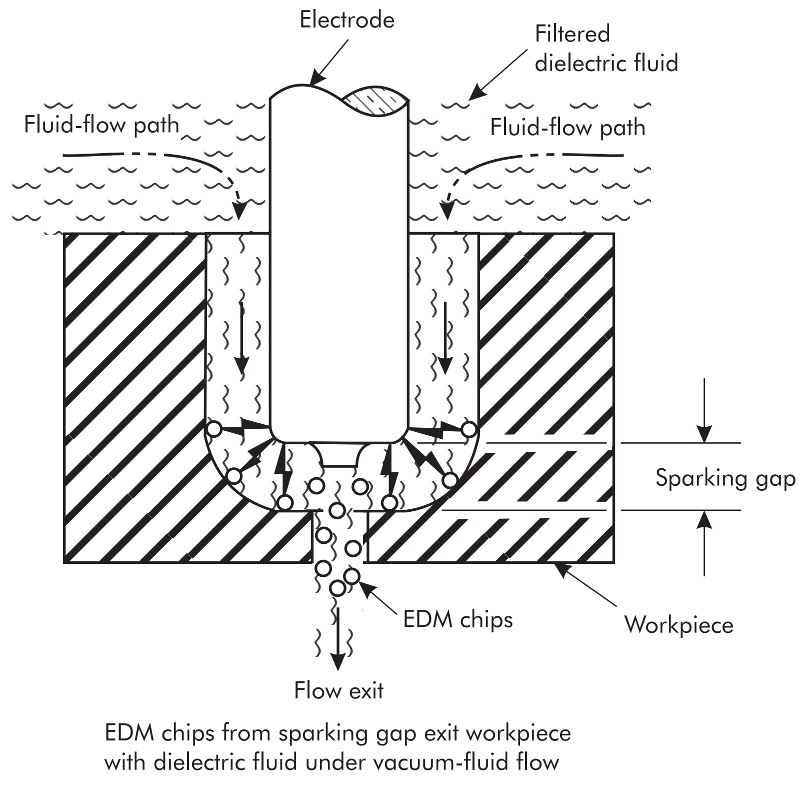


Figure 10-14. Chip removal by vacuum-fluid flow.

sidewalls. It also is possible to achieve these same conditions by causing chips to exit through a fluid-passage hole in the electrode. In either case, side sparking is reduced.

Vacuum flow obtains the dielectric fluid used for chip removal from the machine's work tank. This fluid must be filtered to prevent chips and debris from flowing past the electrode and workpiece sidewalls. Wall tapering from side sparking will occur if unfiltered fluid is used for vacuum-flow purposes.

Vacuum flow does not ensure the total elimination of sidewall sparking, since the fluid passing between the electrode and workpiece sidewalls is not completely filtered. Dielectric filters remove solid material and debris only down to their rated particle sizes. Particles smaller than the rated size pass through the filter element and remain in the fluid. These particles are electrically conductive and occasionally line up to provide a sparking path in the sidewall area. However, the number of side sparks using vacuum flow is considerably less than pressure flow and vertical sidewall tapering is reduced.

How the electrode is attached and mounted to the servo head needs to be considered because vacuum flow resists separation of the electrode and workpiece. This resistance can cause the electrode to pull away from the servo-head mounting as the servo head retracts during the machining operation. In contrast, the pressure applied between the electrode and workpiece from pressure-fluid flow can assist the retraction effort.

WAFER-ELECTRODE DESIGN TO REDUCE TAPER

For applications requiring straight, vertical walls, pressure flow with wafer-type electrodes should be considered. Figure 10-15 illustrates this method.

The wafer-electrode method may require several electrodes to complete the cavity. It is possible to machine multiple electrodes by stacking them before machining them to final size. However, a means of locating them is required, since the worn electrodes must be removed and replaced with the next unused electrode as machining progresses.

The wafer-electrode method reduces sidewall taper by reducing the time of sidewall exposure as the electrode progresses into the workpiece. The benefit of this method is that pressure flow may be used, which allows greater control of the fluid flow than vacuum flow.

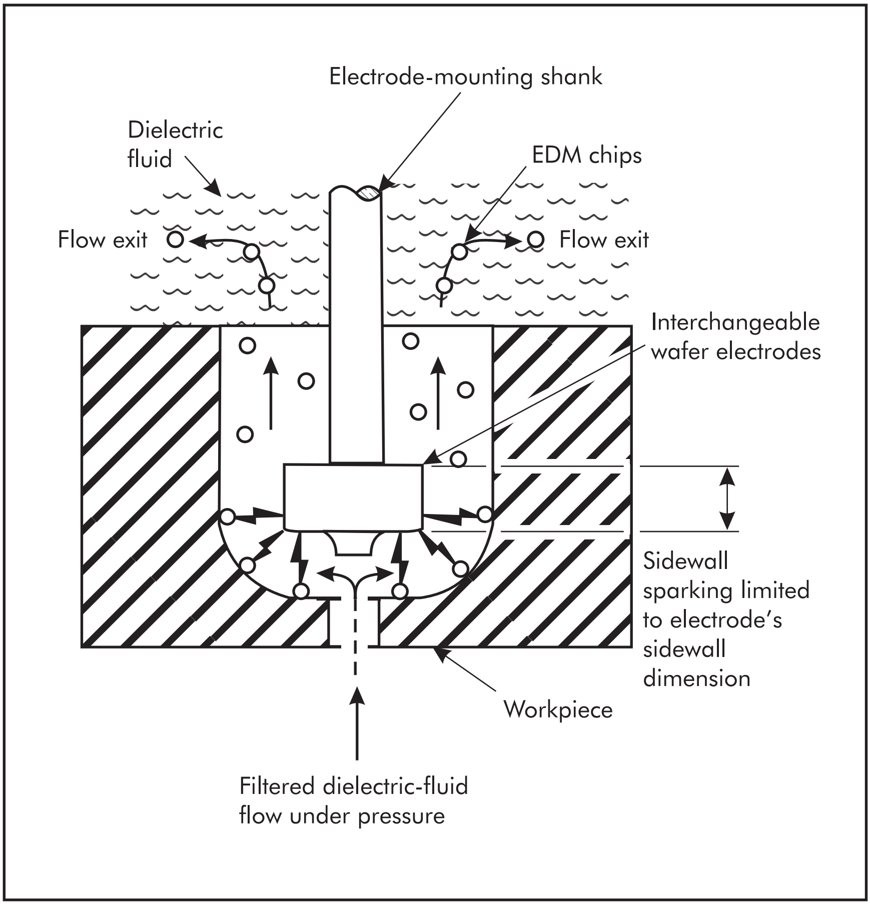


Figure 10-15. Wafer-electrode design for reducing sidewall sparking.

SMOKE AND GAS COLLECTION IN FILTER VESSELS

Vacuum flow removes smoke and gas from the sparking area, along with the chips. Smoke and gas collects in the filter vessel and displaces fluid at the top, reducing the surface area available for fluid filtering. The smoke and gas must be vented from the filter vessel for proper operation of the filtration system. This must be carefully done, since hydrogen is a by-product of the dielectric-fluid breakdown caused by sparking. No heat source should be in the vicinity of the filter vessel during venting to prevent possible ignition of escaping gas.

TAPERED WALLS AND ELECTRODE MISALIGNMENT

Sidewalls that are tapered, or deformed, from electrode misalignment must not be confused with taper from side sparking. Sidewall deformation occurs when the electrode axis is not parallel with the servo-head axis of travel. Figure 10-16 illustrates this condition.

Shapes produced by misalignment of the electrode to the servo-feed axis have sidewalls that appear to be tapered. In reality, the walls are deformed because of the angle at which the electrode enters the workpiece. Additional deformation occurs from electrode corner wear as the electrode proceeds into the workpiece. To perform precise machining, the electrode axis must be exactly parallel to the servo-head feed axis.

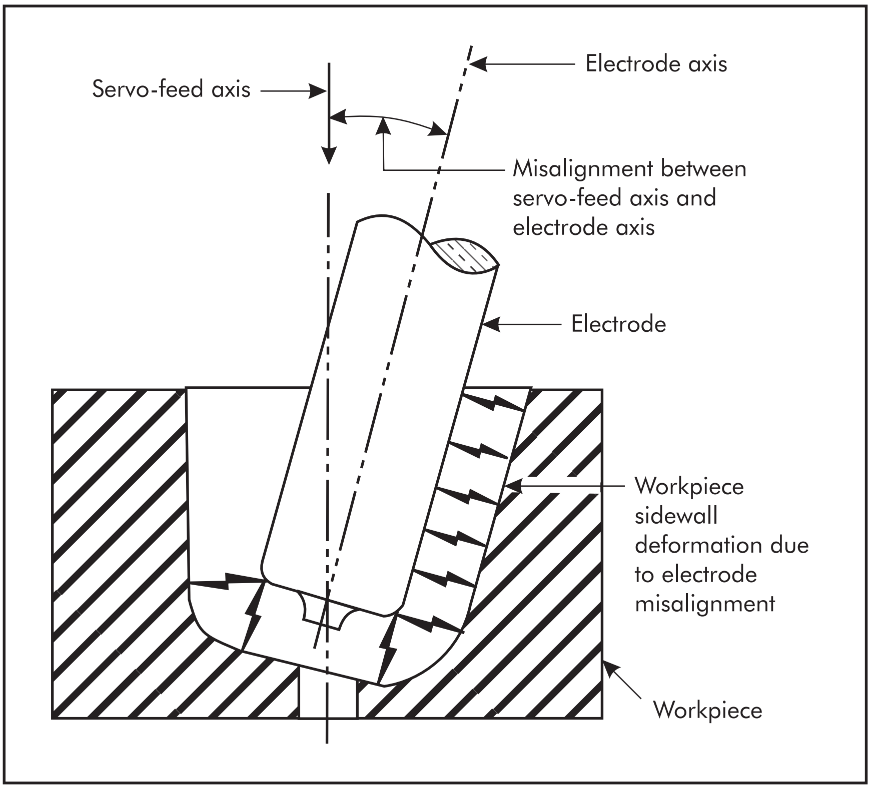


Figure 10-16. Electrode misalignment produces sidewall deformation.

EXTERNAL FLOW FOR CHIP REMOVAL

There are occasions when fluid flow through neither the electrode nor the workpiece is practical. An example is a thin cross-section, blade shape used to machine a rib slot into a three-dimensional cavity. In such an instance, the use of external fluid flow during electrode retraction may be a practical solution. Figure 10-17 illustrates this method.

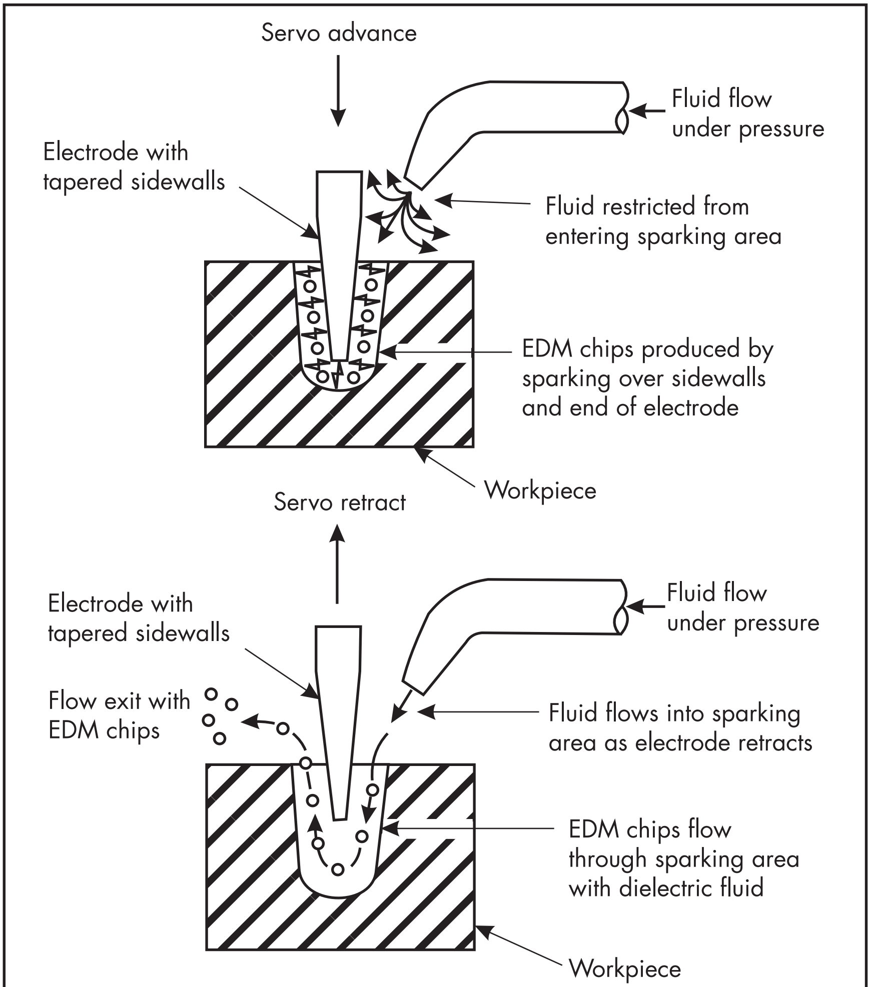


Figure 10-17. External fluid flow during electrode retraction.

CYCLE-INTERRUPTION CHIP REMOVAL

To be practical, the use of external fluid flow for chip removal requires retracting the electrode from the workpiece to open up the electrode-to-workpiece spacing so that fluid can flow into and through the sparking gap. As the electrode retracts, the machining cycle is interrupted; thus, this is often referred to as "cycle-interruption" machining.

Cycle interruption is often a standard—or perhaps an optional—feature on die-sinker EDM machines. The feature uses the machine's servo system with an added feature of causing the servo head to periodically retract. Normally, the time for sparking and the time for retraction are individually set and adjusted. Some cycle-interruption systems include the feature of stopping the fluid flow during the sparking time so that fluid flows only during the electrode's retraction time. This feature eliminates the possibility of applying fluid force against the electrode during sparking time.

Fluid-Nozzle Placement for Chip Removal

Cycle interruption should always be considered when the drilling of fluid-flow holes is impractical. This process can also be used for applications where fluid holes are available, even though the flow pattern does not remove chips efficiently from all of the sparking areas. In this case, an external flow nozzle is normally used to direct fluid so that it removes chips and debris from the sparking area.

The positioning of the flow nozzle determines the efficiency of chip removal and the machining operation. Nozzles should be positioned so that the output of one does not restrict the output of another. Figure 10-18 illustrates the flow restriction that results from using a nozzle on each side of an electrode. This setup causes turbulence in the sparking-area fluid, but it does not allow the fluid to flow through the area as the electrode is retracted. Locating the flow nozzle on only one side of the electrode is preferable. This allows fluid to flow through the sparking area as the electrode is retracted, without creating an opposing fluid force.

Timing for Advance and Retraction

Cycle-interruption fluid flow requires the machinist to set the time for the electrode to remain in the sparking position, as well as the time

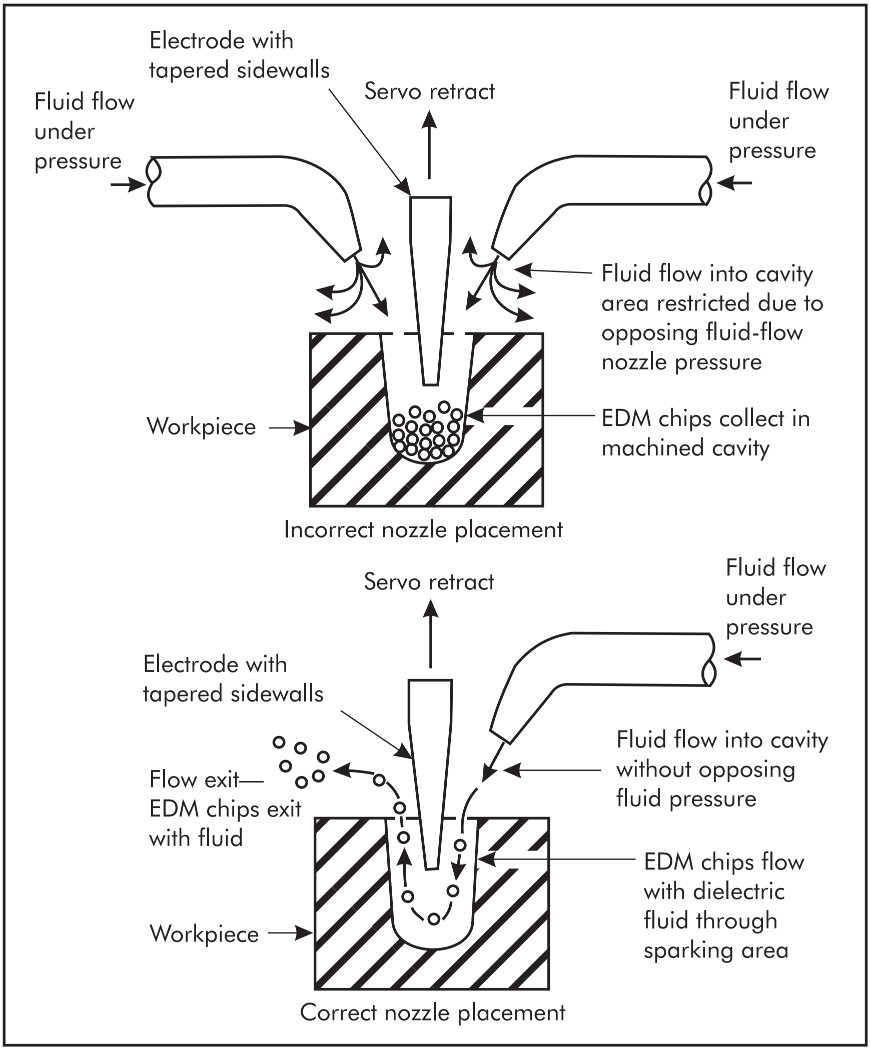


Figure 10-18. Flow restriction from opposing nozzles.

for its retraction. The following guidelines may be used to establish the sparking and electrode retraction times.

- Electrode feed and sparking time: the electrode feed-rate indicator should be monitored. When the servo action becomes erratic from chip build-up in the sparking gap, it is necessary to initiate electrode retraction.

- Electrode retraction time: set the electrode retraction time so that electrode-to-workpiece spacing is sufficient enough to allow fluid to flow through and out the other side of the sparking gap. Initiate electrode advance.
- Make fine adjustments to the in-feed and retraction times after the electrode enters the workpiece a short distance. Further fine adjustments may be required as the electrode advances into the workpiece and the fluid travels a greater distance. Reasonably efficient sparking conditions and servo action can be established using this method.

Cycle interruption works best with an electrode having a sidewall taper that is required in the machined cavity. The sidewall allows the sparking-gap spacing to quickly open for fluid flow. Vertical sidewall electrodes require the complete retraction of the electrode before allowing fluid flow into the cavity. External fluid flow into a cavity may not completely remove the chips and debris from all cavity areas. The machining cycle may have to be stopped occasionally to clean material from these areas. Poor fluid flow is evident by a blackening of the workpiece surface. Should this be observed, the blackening must be removed since it could bring about DC arcing in these areas.

When using an external flow nozzle with cycle interruption, the force of the fluid against the electrode should also be taken into consideration. Thin electrodes can move sideways when force is applied. If the electrodes move during sparking, they could contact the workpiece and result in an electrical short. This causes the electrode to retract until the short is opened, resulting in inefficient machining and erratic servo action, as well as a possible distortion of the machined cavity. The fluid pressure should only be great enough to remove chips and debris, without distorting or moving the electrode.

VIBRATION FOR CHIP REMOVAL

For some applications, it is impractical to provide fluid-flow holes in the electrode or workpiece, such as a coining die with fine detail. Providing fluid-flow holes in either the electrode or the workpiece will destroy detail. In instances like this, electrode vibration should be considered for removing chips and debris from the sparking gap.

CONSIDERATIONS FOR CHIP REMOVAL BY VIBRATION

When using the vibration method of chip removal, the requirements of the machining operation must be considered. The following items are important:

- Electrode sparking area—if an electrode has a large surface area, vibration may not cause enough dielectric fluid to flow to the center area for chip removal. If debris remains in this area, it will cause erratic servo action and possible DC arcing. Cycle interruption flow may be a better solution.
- Electrode weight—electrode-vibration mechanisms usually include a diaphragm that flexes to cause an up-and-down movement. A heavy electrode will dampen the vibration amplitude. If the vibration system is part of the machine's servo system, electrode weight may not be a major consideration.
- Cavity depth—deep-cavity machining may not be practical using electrode vibration. The up-and-down movement of the electrode is very limited. Fluid at the bottom of the cavity may not move to the point of causing the chips to exit the sparking area. Chips and debris have a tendency to settle at the deepest portion of the cavity and to collect so that erratic servo action and DC arcing can occur. Again, cycle interruption flow may be a better solution (see Figure 10-19).

A mechanical assembly, mounted between the servo head and machine work table, may provide the necessary vibration of the electrode. The space that is required for mounting this type of vibrator unit reduces the machine's open height. Another method used for electrode vibration is applying electrical voltage to the servo-feed electrical circuit. This causes the electrode to vibrate from the applied electrical voltage as the servo system advances the electrode toward the workpiece. When vibration is provided by the electrical circuit method, no height is lost between the servo head and machine table. Figure 10-20 illustrates the fluid movement that occurs as the electrode vibrates up and down.

Vibration frequency is normally determined by the voltage frequency of the alternating electricity used for primary input to the machine. Amplitude of vibration is quite small, usually ranging from 0–.010 in. (0–0.25 mm). Since the electrode is moving both toward and away from

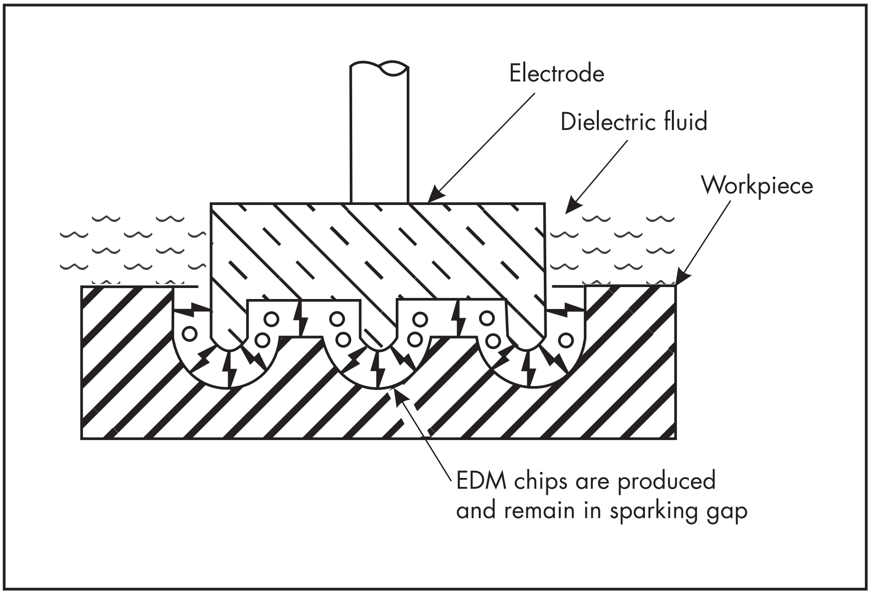


Figure 10-19. Electrode in sparking position.

the workpiece during vibration, sparking occurs only as the electrode advances to the sparking position.

Vibration causes the fluid to be forced out of the sparking area as the electrode advances. As it retracts, fluid again enters the sparking area—although some fluid remains in the space between the electrode and the workpiece at all times. The action of the fluid moving in and out of the sparking area keeps the chips and debris in motion and retards settling on the workpiece surface. Because this type of fluid motion does not provide a positive means of chip removal, it may be necessary to occasionally stop the machining cycle to manually clean the machined surface and ensure acceptable servo efficiency.

When using a mechanical vibration unit, it is important for the axis of vibration to be the same as the servo-head feed axis. If different, there will be a distortion of the machined cavity. The condition of the mechanical unit is also important. Any looseness between the vibrating elements will result in cavity distortion and erratic servo operation (see Figure 10-21).

In most applications where fluid holes are not practical, it is first advisable to consider the use of cycle interruption for chip removal.

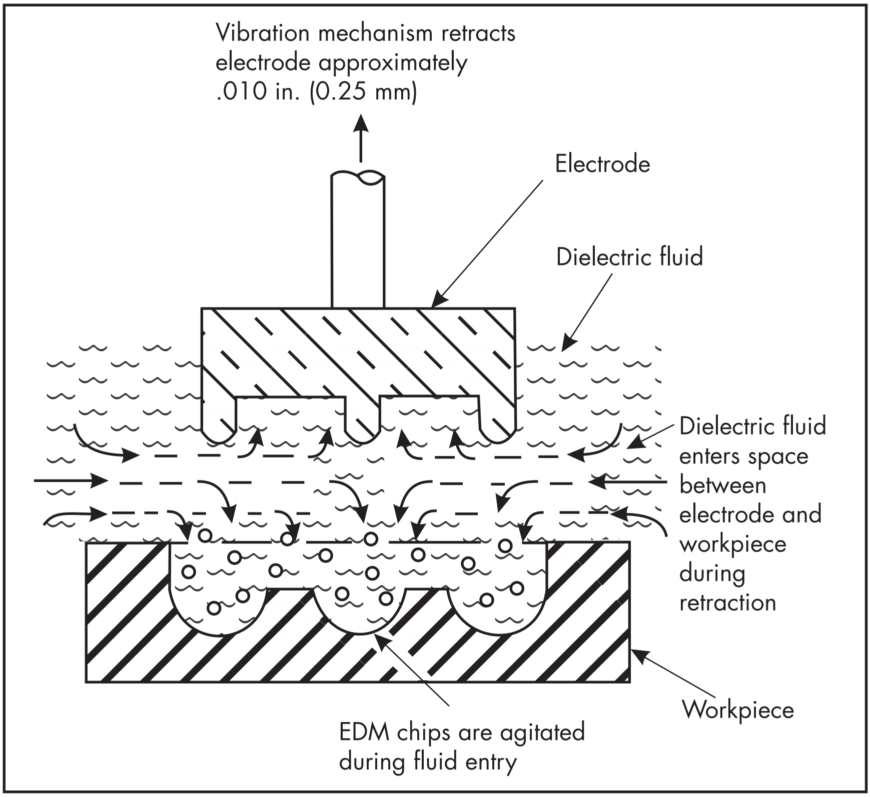


Figure 10-20. Electrode retraction during vibration.

ELECTRODE ORBITING

Electrode orbiting is advantageous since the first electrode used to produce a cavity is made under size by the amount of orbit and by the spark overcut. Consideration must also be given to the amount of material left in the cavity for finish machining.

Orbiting devices may be added as accessories to manually operated die-sinker machines. CNC-controlled die-sinker machines normally include orbiting capabilities in the computer programming. When an orbiting device is added to a machine the open-height distance between the servo-head platen and machine table must be taken into consideration, since the orbiting unit is installed in this space.

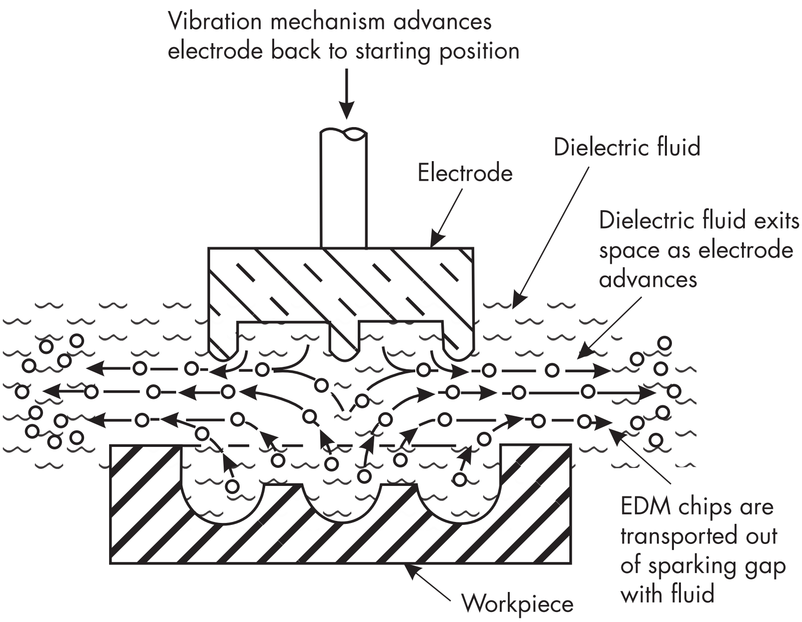


Figure 10-21. Electrode advance during vibration.

Figure 10-22 illustrates basic orbiting patterns, including square, round, cross, and diagonal shapes.

ELECTRODE ORBITING THEORY

The theory behind electrode orbiting is that the sidewalls of the electrode, as well as the electrode end, are used to produce the machined shape. Side machining normally requires much less depth than end machining. In addition, electrode wear is based on machining depth. The reduced electrode wear by sidewall machining requires fewer electrodes to complete the machined form. By orbiting the electrode in a sideway direction, much greater cavity detail is possible from each electrode, compared to that from servo-feed machining without orbiting. In operation, orbiting a roughing electrode while using the no-wear settings may complete the required rough cavity form to the point that only one finishing electrode is required.

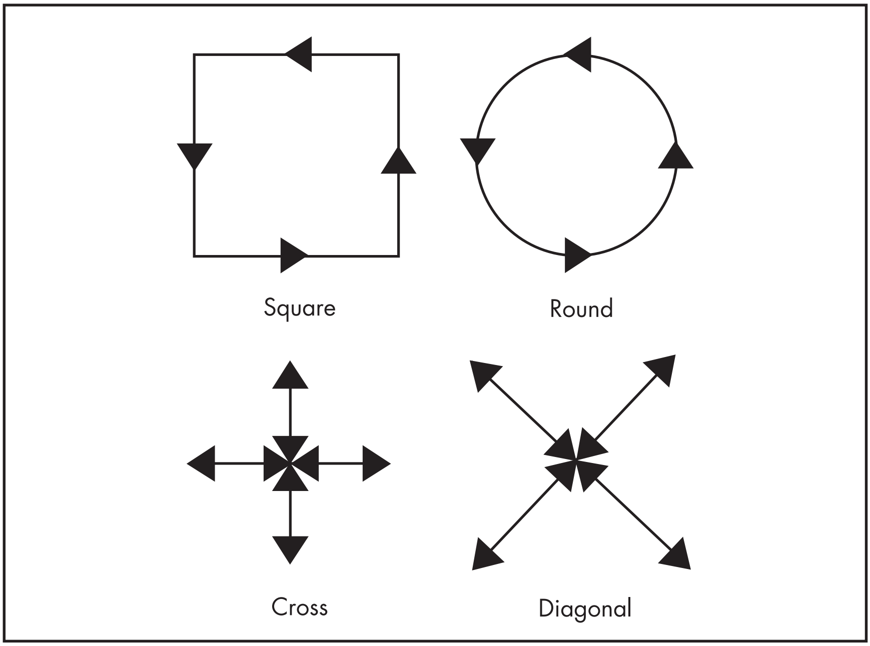


Figure 10-22. Basic orbit pattern shapes.

In considering basic orbiting paths, round and square patterns can be thought of as continuous-path orbits. The diagonal and cross paths normally are fed out from and then back into the center point. Should the servo system receive a retraction command as the electrode is orbiting, the orbiting device is usually programmed to move to a safe position so that physical contact between the electrode and workpiece is prevented.

Orbiting assists in chip removal because the sparking surface is limited. The remainder of the cavity has an opening equal to the amount of orbit plus the per-side spark overcut. This opening allows free flow of the fluid out of the sparking area. The movement of the electrode as it orbits also forces fluid and chips out of this area.

WIRE-CUT CHIP REMOVAL

Chip removal for a wire-cut machine is simple compared to a die-sinker machine. Wire-cut machines include fluid-flow systems that pro-

vide dielectric-fluid flow with pressure to the top and bottom surfaces of the workpiece. The fluid is introduced into the sparking area by nozzles that direct flow into the machined opening. Figure 10-23 illustrates the positioning of the fluid-flow nozzles.

HIGH-VELOCITY FLUID FLOW

Wire-cut machining normally requires high-velocity flow of fluid through the sparking area. The fluid must encapsulate the electrode wire and cover the entire sparking area. As fluid flows through the sparking area and out of the machined opening, the EDM chips are carried with it.

POSITIONING FLUID-FLOW NOZZLES

Fluid-flow nozzles must be positioned very close to the top and bottom workpiece surfaces for effective fluid control and chip removal. If fluid escapes at either surface, less fluid will arrive in the sparking area. Fluid must be supplied to the sparking area so that the electrode wire is completely surrounded with it. This provides the controlled sparking condition required for wire-cut machining. The dielectric fluid also cools the electrode wire that is heated by the wire's sparking and the passage of this spark electricity. Electrode-wire breakage occurs if fluid does not properly surround the wire.

Wire-cut machining is categorized into two classifications:

1. Full-wire plunge machining.
2. Partial-wire finish machining.

Full-wire Plunge Machining

Full-wire plunge machining creates a 180°-sparking area on the electrode wire. Figure 10-24 illustrates this type of machining.

Considerations for full-wire plunge machining center on controlling the fluid as it surrounds the electrode wire. After establishing the machined kerf slot, fluid flow is fairly consistent. But at the start of the machining operation, fluid flow may be difficult to establish. If the electrode wire enters from a surface outside of the workpiece, fluid flow may not be controllable enough to allow efficient machining conditions. In this case, reduced sparking energy should be used until the

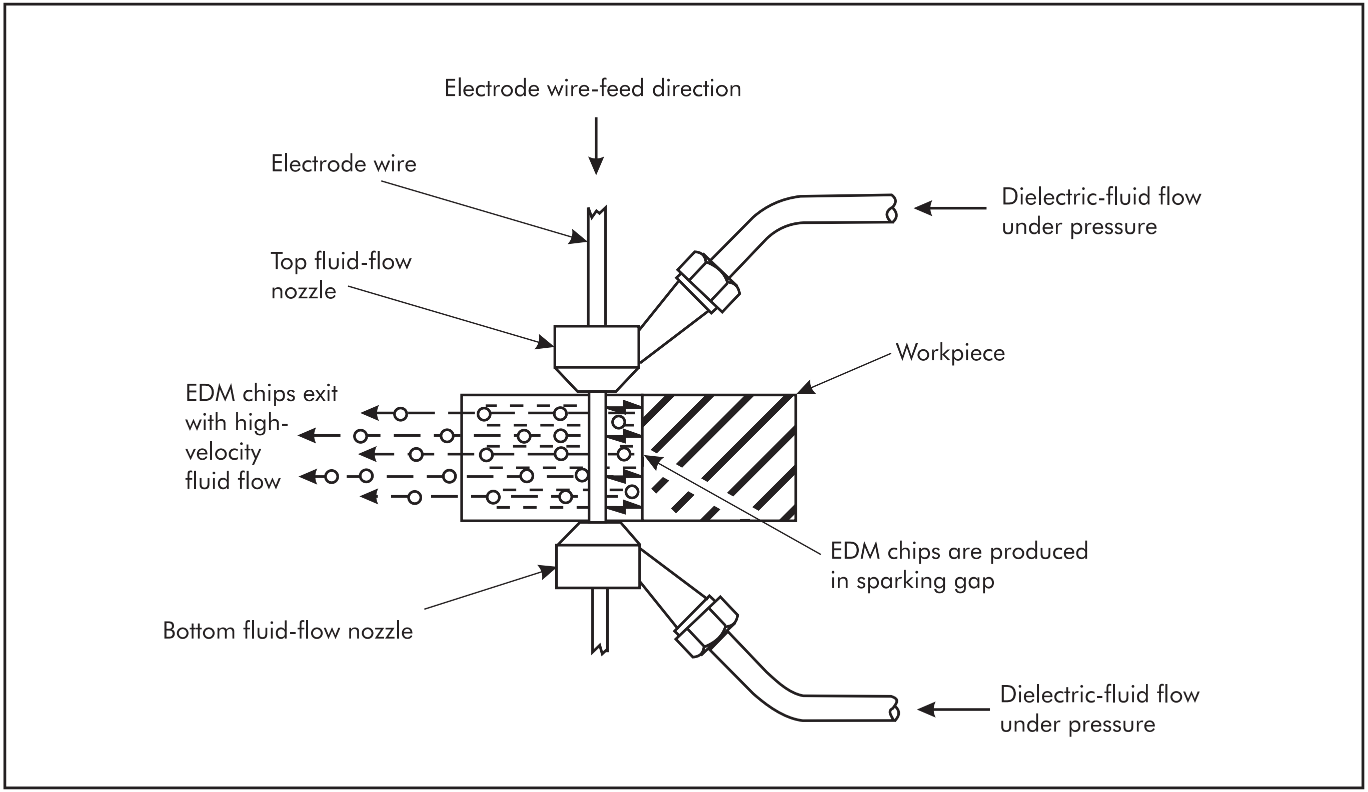


Figure 10-23. Wire-cut fluid-flow nozzles.

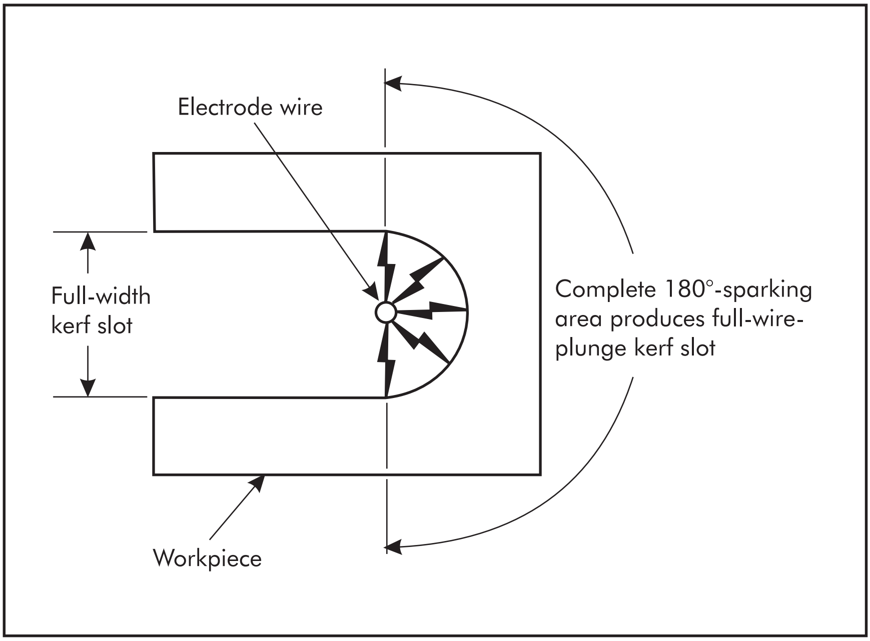


Figure 10-24. Full-wire plunge machining.

wire machines a slot into the workpiece. Otherwise, wire breakage is likely. A preferred method for starting a wire-cut machining operation is to provide a pre-drilled start hole in the workpiece to create positive fluid control by surrounding the electrode wire with fluid.

Minimum Wall Thickness for Fluid Control

Loss of fluid in the sparking area also occurs due to insufficient material at the sides of the machining operation. Figure 10-25 illustrates this condition.

In most machining operations it is desirable to remove as little of the workpiece material as possible. But in full-plunge machining, a certain wall thickness is required for efficient fluid control. A narrow wall does not allow the fluid-flow nozzle to seal the workpiece surface from the fluid coming through the nozzle. Therefore, a wall thickness of no less than .250 in. (6.35 mm) should be used with full-plunge machining. Any thinner can result in escaping fluid, increased machining time, and possible wire breakage.

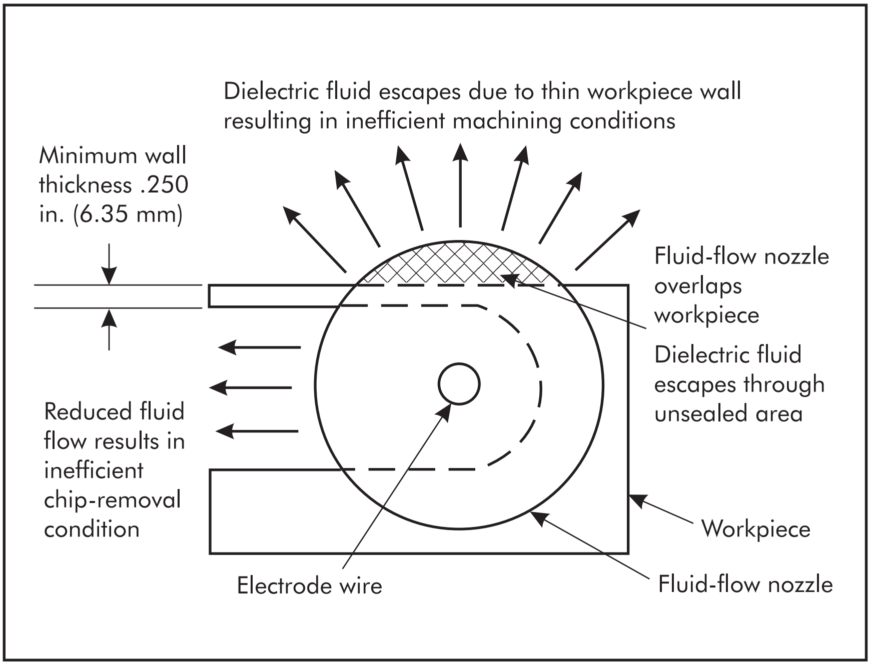


Figure 10-25. Loss of fluid due to narrow wall.

Partial-wire Finish Machining

Partial-wire finish machining provides a sparking area on the electrode wire's diameter of less than 180°. This type of machining is often referred to as *skim cutting.* Partial-wire machining is normally used for the final sizing of the workpiece form and also for providing the required finish on the machined surface. Figure 10-26 illustrates this type of machining.

Partial-wire finishing is often done with the surface to be machined exposed. Sparking can be observed along the complete sparking surface. This type of machining is usually performed using reduced spark energy.

Common practice is to use full-wire plunge machining as a roughing operation, followed by several partial-wire finishing passes over the machined surface. The first pass may be to a depth of one-half the wire diameter; the next pass is made at a depth of one-quarter the wire's diameter. Each pass removes less of the workpiece material at reduced

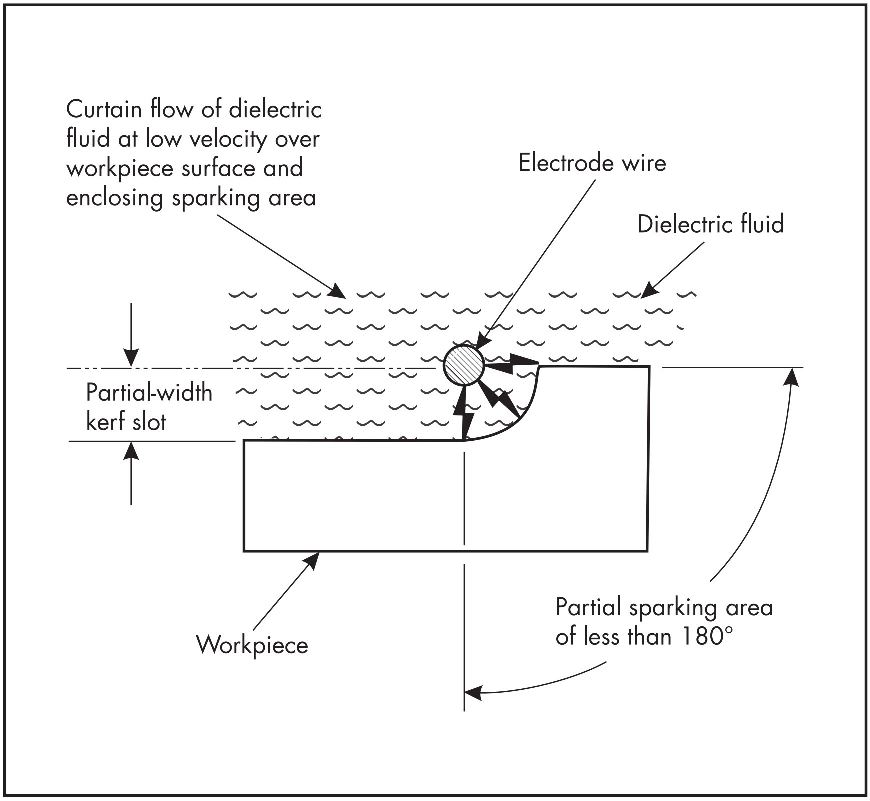


Figure 10-26. Partial-wire finish machining.

spark energy. This procedure provides the final precision and surface finish of the final form required for the machining operation. The number of finish passes and amount of wire offset for each pass is determined by the computer database from information provided at the beginning of the machining operation.

Controlling the dielectric fluid is a major consideration when using partial wire sparking. High-velocity flow is used for full-wire plunge machining, but is not acceptable for partial-wire machining, which does not have an enclosed sparking area. In partial-wire machining, a curtain of fluid covers the workpiece in the sparking area and encloses the electrode wire. Chips are carried away with the fluid as it flows past the machined surface. Fluid flow for partial-wire machining is at a much lower velocity than full-wire machining.

SUBMERGED MACHINING

It is not always possible to have a workpiece with flat, parallel top and bottom surfaces. Irregular surfaces do not allow positioning of the flow nozzles for positive fluid flow in the machining area. Such shapes either deflect the fluid-flow path, cause stagnation of the fluid in the sparking area, or produce inefficient machining conditions and wire breakage. Fluid flow coming only by way of the nozzles is not sufficient under these circumstances. Submerging of the workpiece, in addition to the use of nozzle fluid flow, is often required to improve these types of machining conditions.

SUMMARY

Wire-cut chip removal is assisted by the computer database in the machine's control. The EDM-part programmer enters precision and surface finish information required in the machined form prior to starting the machining operation. The machine's computer analyzes this data and provides suggested machine and control settings.

EDM manufacturers provide a variety of fluid-flow nozzles to suit different machining conditions. Nozzles are available for angle machining where the wire does not continue in a straight-line path as it moves through the nozzles. Nozzles are also available that seal against and then follow an irregular surface within some travel limits. All EDM-wire-cut manufacturers provide training and application assistance regarding proper chip-removal techniques and the control of dielectric fluid required for efficient machining operations.

Spark Energy Transmission

11

This chapter covers the electrical connections required for sparking and machining energy in EDM operations.

POWER SUPPLY AND MACHINE ELECTRICAL CONNECTION

The EDM-power supply produces sparking electricity to the electrode and workpiece for EDM operations. Connecting the power supply to the electrode and workpiece might seem to be a simple matter of connecting one wire from the power supply to the electrode and another wire from the power supply to the workpiece. Figure 11-1 illustrates these electrical connections. However, it is not possible to

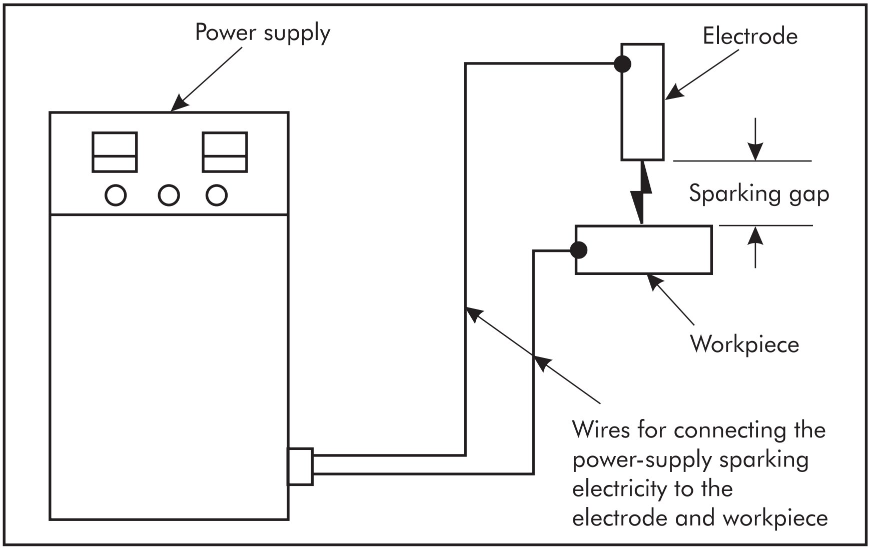


Figure 11-1. Electrical connections between power supply, electrode, and workpiece.

connect separate wires as illustrated and still produce efficient machining conditions when the electricity is turned on. This is because a magnetic field develops around the wires that impedes the flow of electricity. Figure 11-2 illustrates this magnetic field.

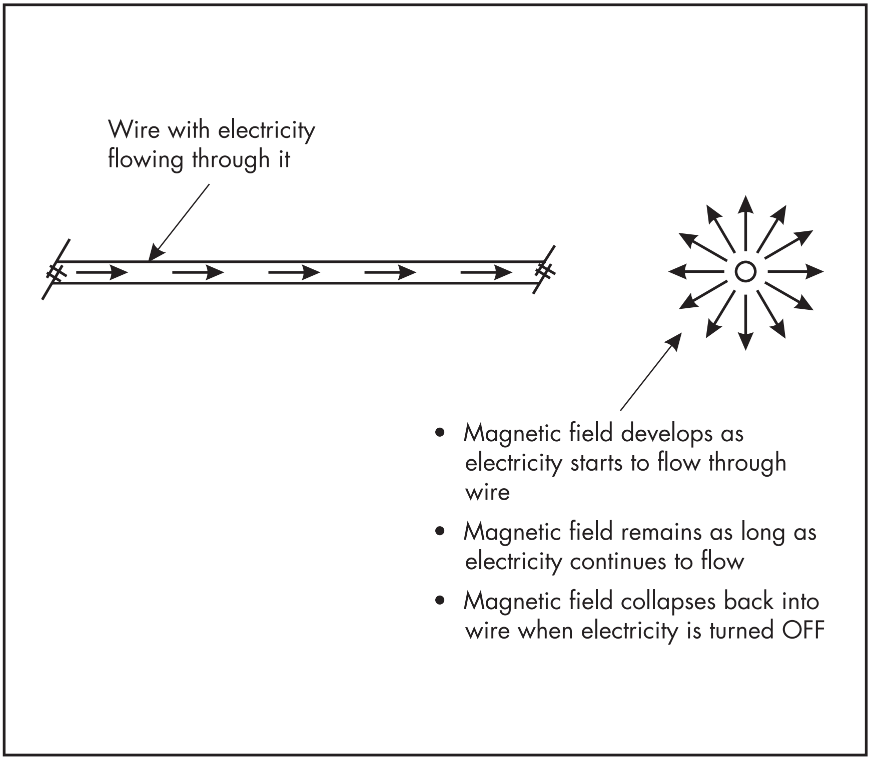


Figure 11-2. Magnetic field around a wire with electricity flowing.

SPARKING-POWER WIRES AND MAGNETIC FIELD

When the electricity is turned ON, a magnetic field develops and expands around the wire. As the magnetic field expands, it impedes the flow of electricity in the wire. When electricity is flowing and the magnetic field has developed, it flows without restriction. When the electricity is turned OFF, the magnetic field collapses back into the wire, which causes the electricity to continue flowing after the turn-OFF point. Figure 11-3 illustrates this condition.

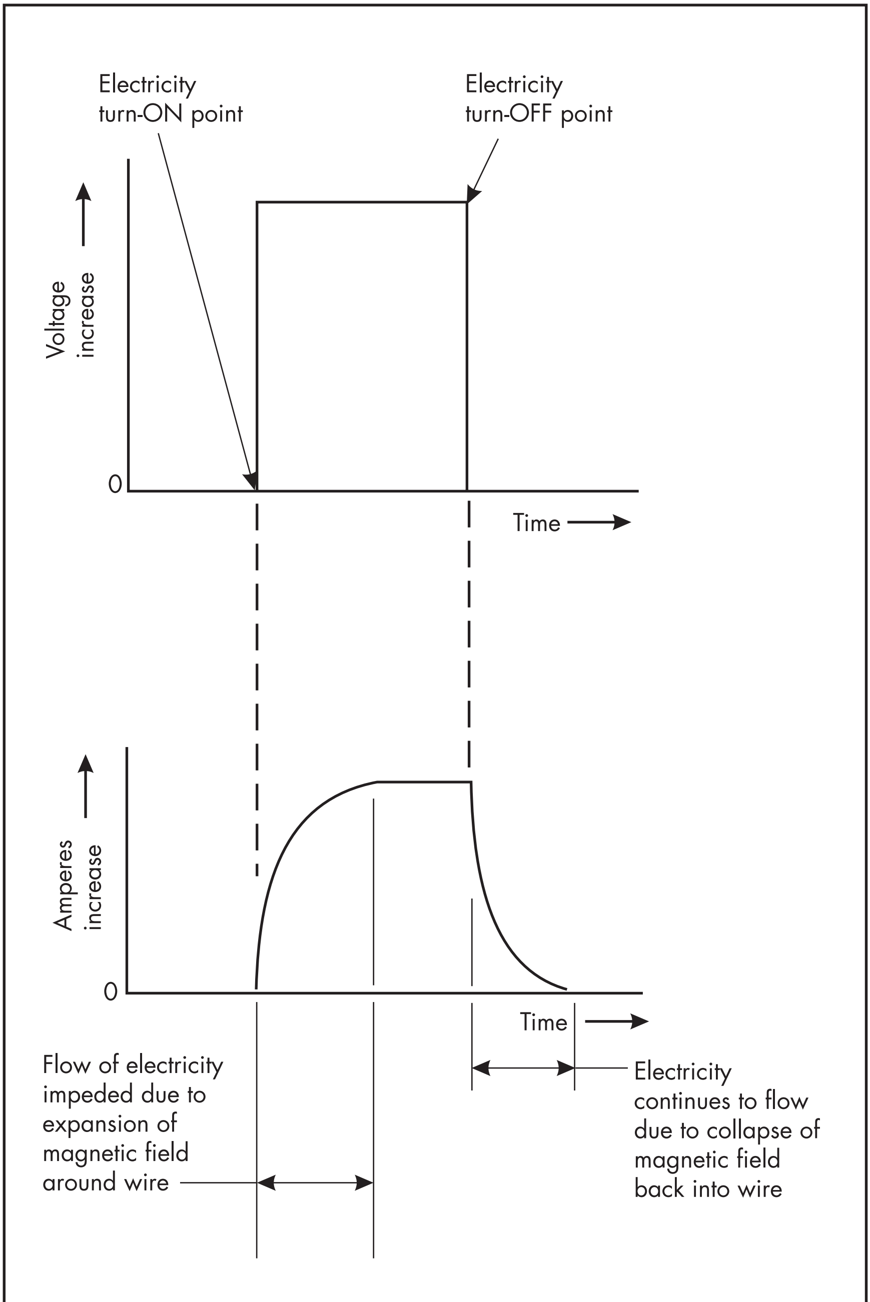


Figure 11-3. Effect of magnetic field on flow of electricity.

Inductive Reactance

The electrical term for impeding the electricity at turn ON and continuing the flow at turn OFF is *inductive reactance*. The formula for determining inductive reactance is:

$$X_L = 2\pi f L \qquad (11\text{-}1)$$

where:

X_L = inductive reactance (ohms)
π = 3.14
f = frequency (sparks per second)
L = inductance (henrys)

This formula shows that inductive reactance increases as spark frequency increases when inductance is a constant for a particular situation with π being a known constant.

Sparking Frequency

The spark-ON and -OFF times determine spark frequency. The formula for determining spark frequency is:

$$F = 1{,}000{,}000/(ON + OFF) \qquad (11\text{-}2)$$

where:

F = spark frequency (sparks per second)
ON = spark-ON time (microseconds)
OFF = spark-OFF time (microseconds)

Examination of this formula shows that spark frequency increases as spark-ON and -OFF times decrease.

EDM-design engineers need to consider that large amounts of sparking electricity pass from the power supply to the electrode and workpiece at reasonably high spark frequencies—from 2,000–500,000 sparks per second. Sparking electricity varies from a fraction of an ampere to over 100 A. Ideally, the spark electricity and spark voltage should turn ON and OFF at the exact same instant. But this condition does not occur, due to the inductive reactance of the sparking-power transmission cable.

SPARKING-POWER TRANSMISSION-CABLE DESIGN

The sparking-power transmission cable is designed to minimize the affect of inductive reactance on the waveform of the individual spark pulses. EDM engineers design this cable in such a manner that the magnetic field from the electrode wire cancels the magnetic field from the workpiece wire. The end of the cable that connects to the electrode and workpiece does not benefit by this cancellation, since the two wires are separated. Figure 11-4 illustrates the sparking-power transmission-cable design.

DC ARCING

The principal area of concern for the EDM machinist is the end of the cable that includes the individual electrode and workpiece sparking wires. Increasing spark frequency, while maintaining high machining amperes, may cause the waveform from one spark to connect

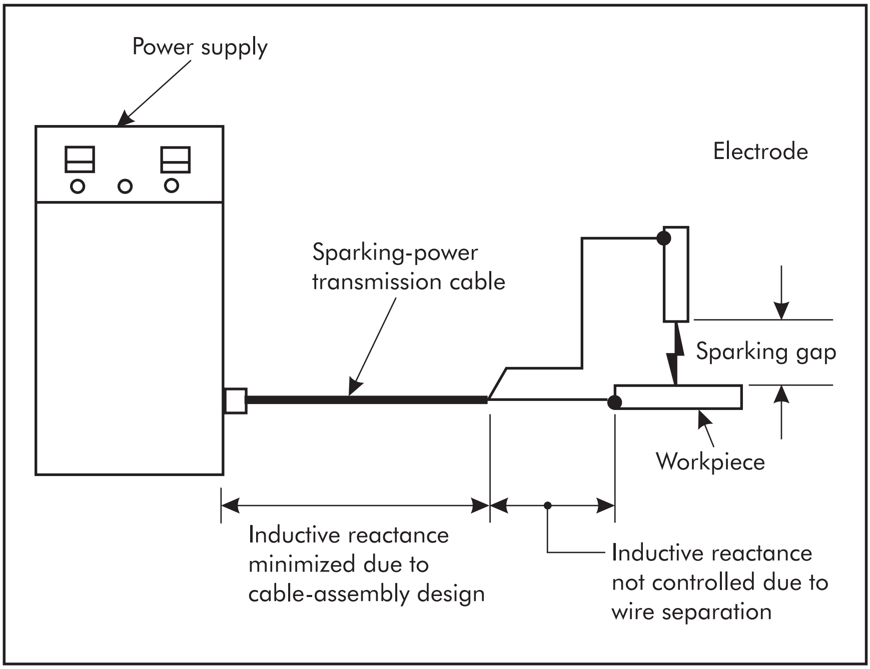


Figure 11-4. Sparking-power transmission-cable design.

with the waveform from the next spark. Figure 11-5 illustrates this condition.

When spark electricity continues flowing from one spark and connects into the next, sparking continues at that single location rather than moving to a new location for the following sparks. This is known as *DC arcing* and can cause damage to the electrode and workpiece. DC arcing occurs because a continuous flow of electricity does not allow the dielectric fluid to deionize.

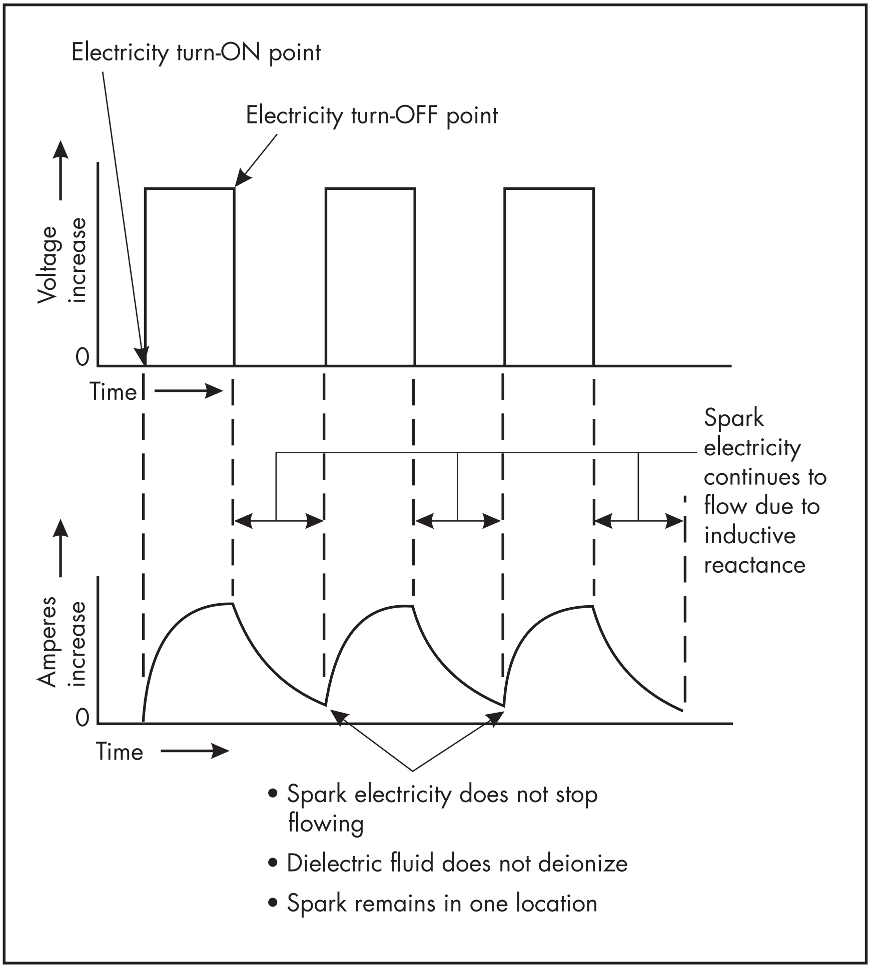


Figure 11-5. Inductance causes continuance from one spark to next.

To prevent DC arcing due to inductive reactance, it is advisable to keep the electrode and workpiece wires as close together as practical, which offers some measure of magnetic field cancellation. It is also always advisable to start the machining operation using a long spark-OFF time, allowing time for the spark electricity to go to zero and the dielectric fluid to deionize. Most EDM manufacturers make minimum spark-OFF-time recommendations, based on peak ampere and spark-ON-time settings. As the machining operation proceeds, it may be possible to reduce spark-OFF time, but it should be done carefully to prevent causing a DC arc.

When EDM operations are performed in a large EDM machine, it is possible that the manufacturer will limit the minimum setting of the power-supply's spark-OFF time. Electrode and workpiece wires can become quite long, making it difficult keep them close together. Allowing only a long spark-OFF time reduces the possibility of DC arcing from the long wire length.

In the event that the sparking-power transmission cable requires replacement, only cable that is approved by the machine manufacturer should be used. It also is important to note that using extensions on the electrode or workpiece wires will increase the inductive reactance that can lead to DC-arcing conditions.

USE OF CAPACITORS AT SPARKING GAP

There are EDM machines in use that include a condenser assembly with wires that connect to the electrode and workpiece. These condenser assemblies are also referred to as *capacitor* assemblies. The condenser assembly discussed in this instance is not part of an R-C-power supply but is an addition to a pulse-type unit. Manufacturers that provide this type of assembly with the power supply use capacitors to overcome the inductive-reactance effect of the sparking-power transmission cable. When inductive reactance equals capacitive reactance, the only obstruction to the flow of electricity is the electrical resistance of the circuit components. Resistance does not change the waveform with regard to the flow of electricity as the sparking voltage is turned ON and OFF. Figure 11-6 illustrates a typical diagram of condenser assembly wiring.

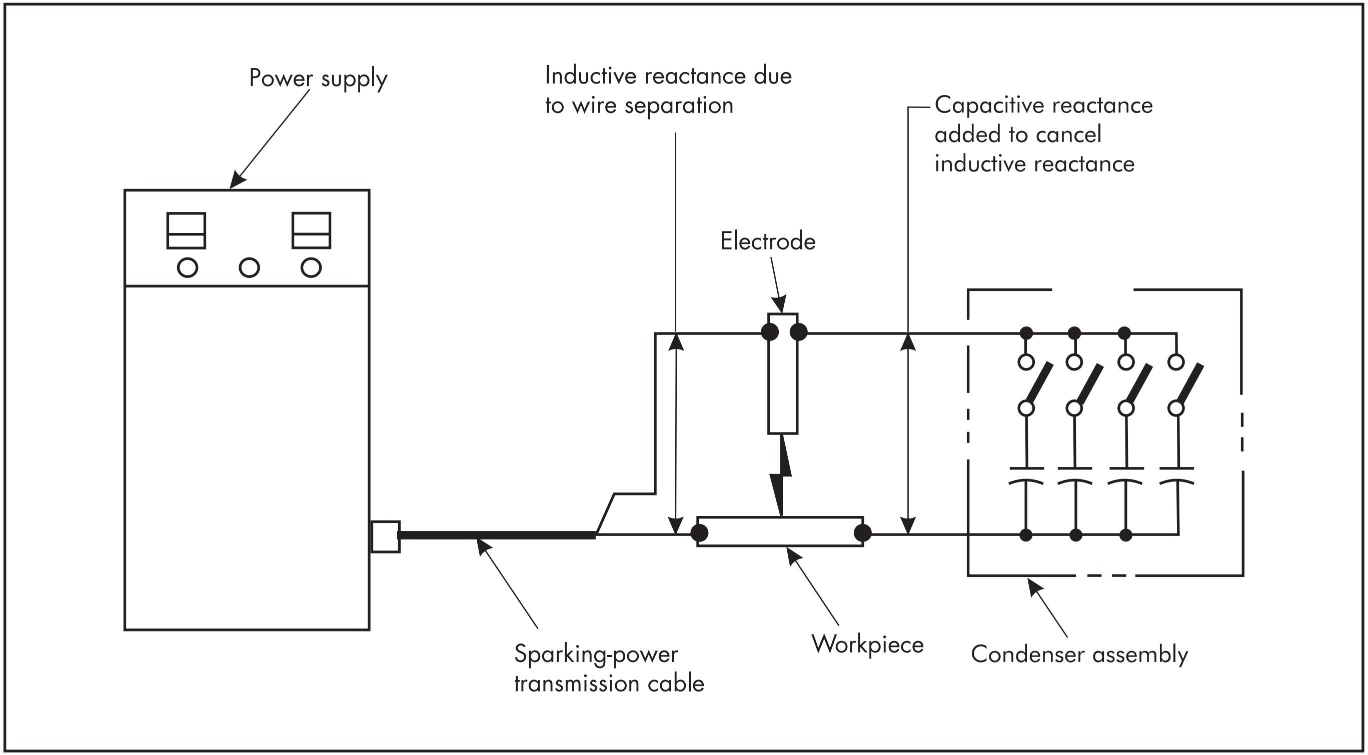


Figure 11-6. Condenser-assembly wiring diagram.

The condenser assembly includes capacitors in a range of electrical sizes. The capacitors can be turned ON as individual units or turned ON collectively as multiple capacitors. In operation, the EDM machinist turns on a small value of capacitance and then continues to increase this value by turning on additional switches. As the capacitive reactance cancels out the inductive reactance, the machine operation stabilizes and sparking sound changes from intermittent to continuous. It is important for the EDM machinist to observe the machine manufacturer's capacitor-use recommendations because misuse can cause DC-arcing conditions.

Capacitors should not be used with or added to an EDM machine without the approval of the machine manufacturer. Adding capacitance between the electrode and workpiece may damage the power-supply and servo-system components.

SUMMARY OF INDUCTIVE REACTANCE

The following points summarize what happens with inductive reactance:

- inductive reactance increases as spark frequency increases;
- inductive reactance causes the trailing edge of the spark waveform to extend;
- extension of the waveform trailing edge decreases the time from one spark to the next; and
- when the trailing edge extension increases to the point that it connects with the next spark, DC arcing will result.

ELECTRICAL CONNECTIONS

The electrical connection of the sparking-power transmission cable to the electrode and workpiece is very important. A poor connection may reduce the sparking energy due to the high resistance between the sparking-power cable, the electrode, and workpiece. The result of this poor connection is unacceptable machining conditions.

In addition to transmitting sparking power from the power supply to the electrode and workpiece, an electrical connection from the servo system to the electrode and workpiece is often included in the sparking-

power cable assembly. When this design is used, high resistance or loose electrical connections can affect the operation of the servo system as well. The servo-system wires may be supplied as a separate cable assembly or even connected internally within the power supply. When internal wiring is used, no additional outside servo-cable wires are required. Figure 11-7 illustrates the electrical connections for separate sparking power and servo-control cables.

When the sparking-power and servo cables are separate, it is possible to visually inspect the condition of the cable terminations. When the servo-sensing wires are included in the sparking-power cable assembly, it makes a visual inspection more difficult.

The machine end of the sparking-power and servo-sensing cables operates in a very hostile environment. Dielectric fluid covers or is splashed on the cables, and the cables are continually flexed. The electrical conductors and termination components can be expected to fail over long periods of operating time.

LOSS OF SPARKING POWER FROM RESISTANCE

Poor electrical connections increase electrical resistance at each mechanical juncture. Figure 11-8 illustrates this concept by showing water as it escapes through the holes of a garden hose. The escaping water represents what takes place in an electrical circuit.

The holes in the garden hose allow water to escape, thus reducing the pressure and amount of water at the hose output. In the same manner, each electrical juncture point of an electrical circuit has some electrical resistance. This resistance reduces the spark-machining voltage, as well as the amount of electricity available to the spark.

The electrode and workpiece wires should be connected as close to the sparking gap as practical and there should be as few electrical connections as possible between the electrode and workpiece wire-connection terminals and the sparking gap. It is possible to have a multitude of electrical connections between the cable connections and sparking gap. Figure 11-9 illustrates mechanical junctures that electricity must pass through to reach the sparking gap. Should there be high resistance or looseness at any junction, sparking energy is reduced and erratic servo action is possible.

Holes in a water hose are comparable to resistors in an electrical circuit. Each mechanical junction includes some electrical resistance.

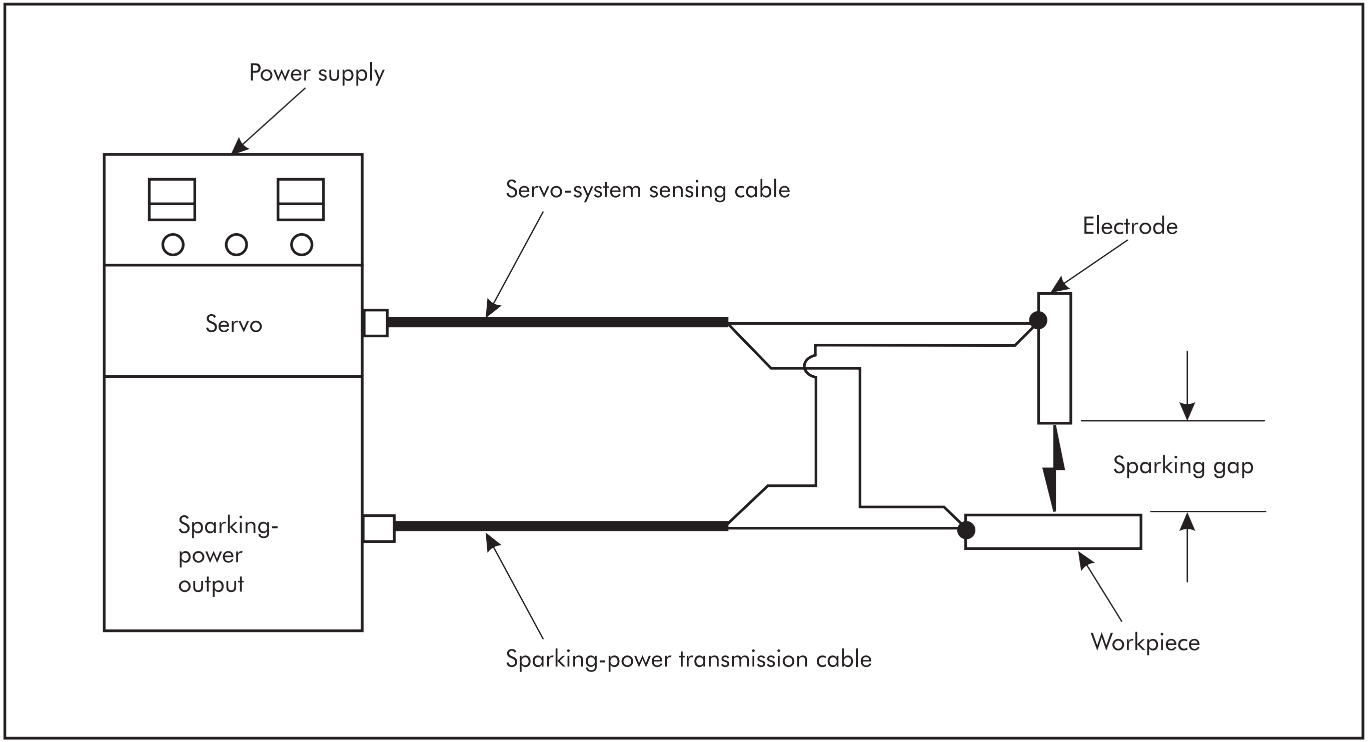


Figure 11-7. Sparking-power and servo-system electrical connections.

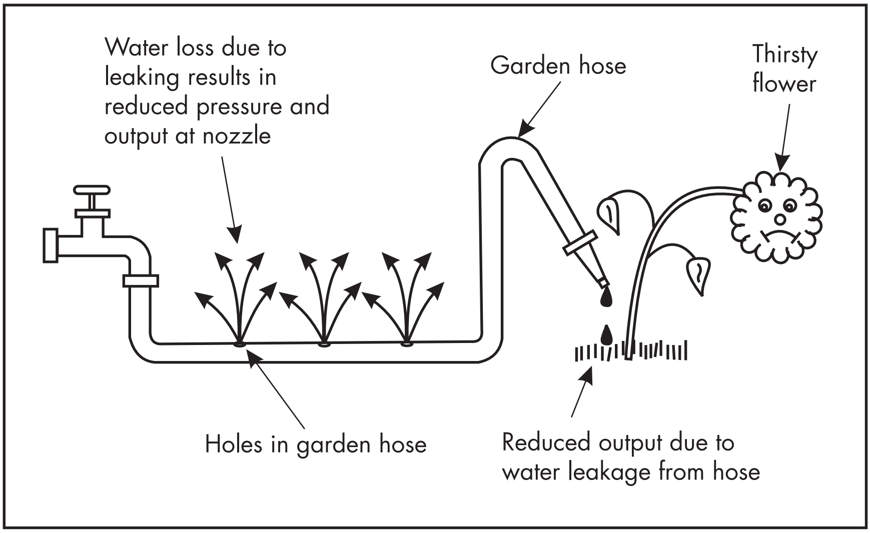


Figure 11-8. Holes in a garden hose reduce water pressure and output.

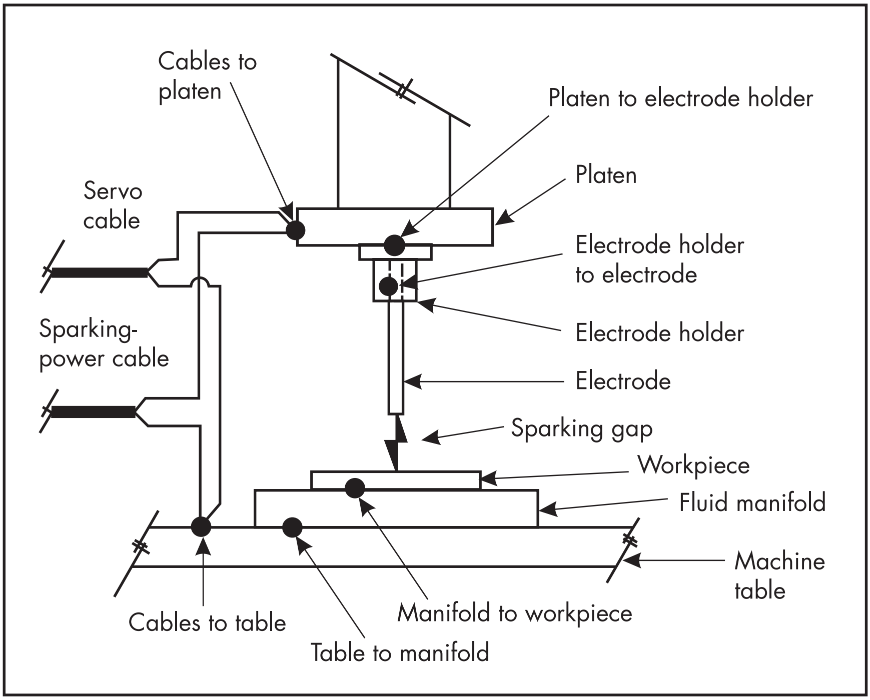


Figure 11-9. Possible mechanical junctures between cables and sparking gap.

Figure 11-10 illustrates the electrical sparking circuit with the resistance included for the mechanical junction points.

Electrical losses from resistance reduce sparking voltage and energy. Keeping the number of mechanical junctions to a minimum, keeping them clean, and making certain they are tight assure the best conditions for sparking and servo stability.

ELECTRICAL RESISTANCE AND HEATING

Resistance in any electrical circuit causes heating. If any electrical connection point feels hot to the touch, it should be inspected, cleaned, and re-tightened. However, sparking power should always be turned OFF before touching any of the electrode and workpiece components or before wiring connections to eliminate the possibility of electrical shock.

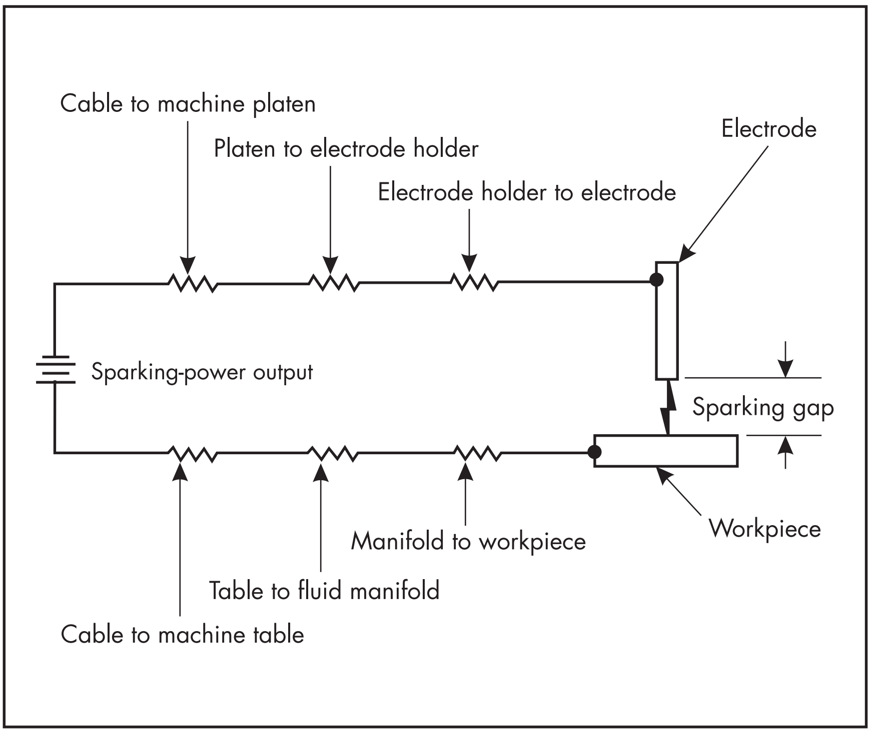


Figure 11-10. Electrical diagram showing resistive mechanical juncture points.

WIRE-CUT ELECTRICAL INDUCTANCE AND CONNECTIONS

The preceding comments and descriptions principally involve die-sinker machines. Wire-cut machines have the same inductive-reactance and resistive-juncture concerns as die-sinker machines, except that wire-cut operations are more controlled.

MACHINE TERMINATION POINTS

For efficient machining operations, wire-cut termination points need to be properly maintained. The electrode-wire sparking power is normally provided by two electrical contacts—one above and the other below the workpiece. This placement allows sparking electricity to flow from both contacts to the sparking gap. If either contact stops conducting electricity, the total amount of sparking electricity (or double the original amount) can flow through the remaining contact and electrode wire, overheat, and break the wire.

SPARKING-POWER CABLE MAINTENANCE

The wire-cut sparking-power transmission-cable terminal on the machine table should also be properly maintained for a positive electrical connection. If this terminal becomes dirty, it will add resistance to the sparking-power electrical circuit and produce unacceptable machining conditions.

TRAVERSE SPEED AND POOR ELECTRICAL CONNECTIONS

The machining-traverse speed of the workpiece is normally controlled by the machine's computer. It is modified during operation to suit machining conditions. Modification is accomplished by feeding the electrode-to-workpiece sparking voltage back into the computer. If there is looseness or high resistance in the electrical connections of the voltage-feedback electrical circuit, unacceptable machining conditions will occur.

DC ARCING

DC arcing is normally not a problem with wire-cut machines, since the electrode wire moves continuously through the sparking area, and since the upper and lower fluid-flow nozzles provide a steady flow of fluid. But if fluid-flow conditions become unacceptable, the wire will normally break.

12 The EDM Surface

The surface produced by EDM sparking is non-directional and non-reflective and is made up of many spherical cavities. The size of the spherical cavities depends on the melting temperature of the workpiece, the electrical power contained in the spark, and how long the electrical power is applied to the workpiece surface. Workpieces with high melting temperatures will have less material removed for each spark than materials with lower melting temperatures.

SPARK ENERGY

Spark energy is determined by the amount of electrical power contained in each spark, multiplied by the amount of time the electrical power is flowing. The equation for determining spark energy is:

$$W_t = E \times I \times t \tag{12-1}$$

where:

W_t = watt time (microseconds)
E = sparking voltage
I = peak amperes
t = spark-ON time (microseconds)

For any particular application, the sparking voltage is considered constant since it is primarily determined by the characteristics of the dielectric fluid used. When sparking voltage is maintained at a set value, the peak spark amperes, multiplied by the spark-ON time in microseconds, determine spark energy. The two primary conditions that determine spark energy are when:

1. Maintaining spark-ON time, spark energy is increased as peak spark amperes are increased.
2. Maintaining peak spark amperes, spark energy is increased as spark-ON time is increased.

Figure 12-1 illustrates the increasing of spark energy through the increasing of spark-ON time. This illustration is based on maintaining sparking voltage at 30 V and the spark's peak amperes at 10 A. When these conditions are held constant, sparking power is increased as spark-ON time is increased. Spark energy is determined by the amount of time that the sparking power is applied. As spark-ON time or peak amperes are applied over a longer period of time, spark energy is increased and the spark removes a larger volume of the workpiece surface. Figure 12-2 illustrates the increase of spark energy as spark-ON time is held constant and peak amperes are increased.

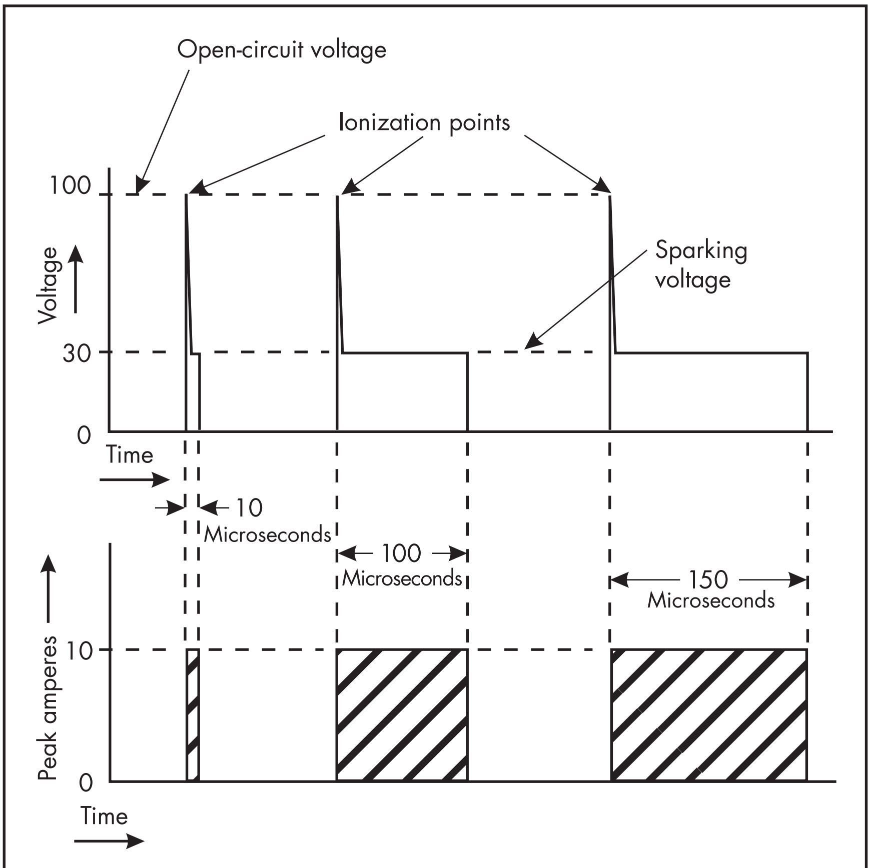


Figure 12-1. Increasing spark energy by increasing spark-ON time.

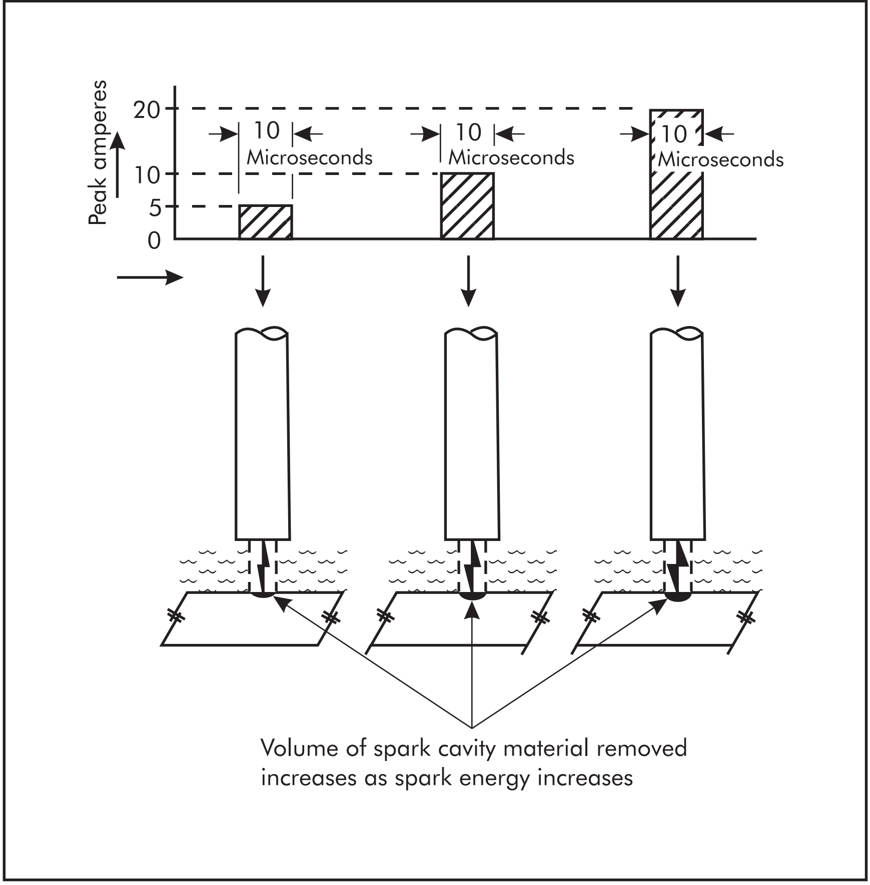


Figure 12-2. Increasing spark energy increases surface roughness.

The EDM machinist normally sets two controls to produce a particular surface finish. From data provided by the machine manufacturer, spark-ON time and peak spark amperes are set to provide the required spark energy. Electrode polarity also will be specified.

Spark-machining voltage is normally adjusted to provide a stable servo operation after the sparking operation starts. Machining voltage is primarily determined by the dielectric strength of the fluid used—normally in a range of 20–50 V. Once the servo operation is stable, the machining voltage normally remains fairly constant. Based on a constant machining voltage, spark energy is then determined by the peak amperes and spark-ON-time settings.

DETERMINING SURFACE FINISH

Since peak spark amperes and spark-ON time are the principal factors in determining spark energy, the following effects exist:

- an increase in either peak amperes or spark-ON time increases spark energy;
- an increase in spark energy increases the volume of workpiece material removed by the spark; and
- an increase in the volume of workpiece material removed by the spark results in a coarser EDM surface finish.

ELECTRODE SURFACE IMPERFECTIONS

The electrode's sparking surface is reproduced in the exact opposite form as that of the workpiece. If this surface is scratched, a raised line will be produced into the machined surface of the workpiece.

The EDM surface is also affected by the structure of the electrode material. If it is a coarse-grain substance with voids between the grains, this surface condition will be reproduced on the machined surface of the workpiece. To create the finest EDM surface, a metallic electrode material should be used, such as copper, with an electrode surface finish at least equal to the desired workpiece surface finish.

VARIATION IN SPARK-CAVITY SIZE

While EDM-surface-finish sparking is normally thought to produce spherical cavities of uniform diameter and depth, this is not a true representation of most actual EDM-machined surfaces. Spark-ON time is not always equal for all sparks because the spark-ON-time set at the power-supply control may be quite different than the actual spark-ON time. Figure 12-3 illustrates how this occurs.

Spark-ON and -OFF time is set at the power supply's control panel in fixed microsecond pulses. Ideally, each spark occurs instantaneously at the beginning of the spark-ON time, as directed by the power supply control. It is possible, though, that the electrode is not in close proximity to the workpiece. In this instance, the dielectric fluid does not ionize and the spark does not occur.

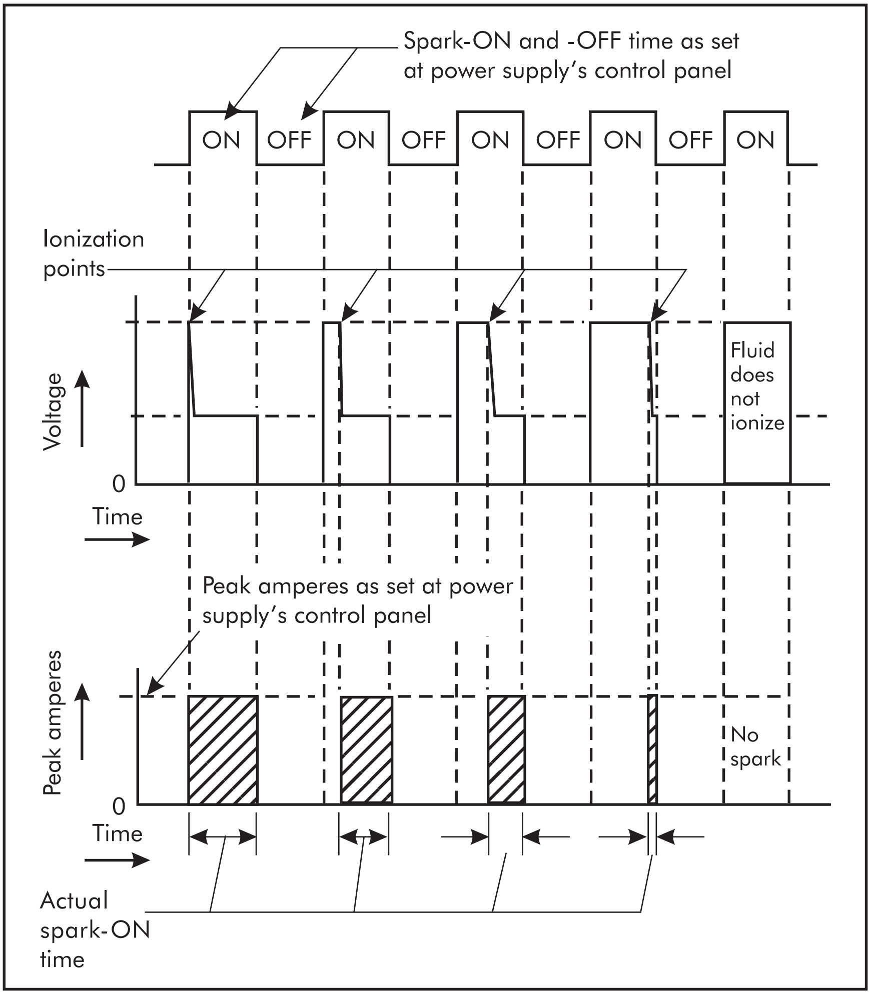


Figure 12-3. Actual spark-ON time determined by the dielectric fluid's ionization point.

Sparks occur only when the dielectric fluid ionizes. The process requires these conditions:

- open-circuit voltage must be present between the electrode and workpiece;
- open-circuit voltage between the electrode and workpiece exists only during the time that the power supply control provides for spark-ON time;

- the sparking gap must be filled with dielectric fluid; and
- dimensional spacing between the electrode and workpiece must be a correct distance to allow ionization of the dielectric fluid.

Since the dielectric fluid's ionization point actually controls the starting point of each spark, it is possible to have the spark begin at any time during the power-supply-controlled spark-ON time. If ionization occurs after the power-supply control's directed spark-ON time, the energy of the actual spark is reduced due to the reduction in actual spark-ON time. This reduction in spark energy reduces the volume of workpiece material removed and results in a smaller spark cavity than the one created by a full energy spark. Spark cavities, therefore, vary in size.

Since all sparks do not have the same actual spark-ON time, the surface finish produced consists of spark cavities of different sizes. The largest spark cavity, however, will be the size of a full ON-time spark as determined by the power-supply control's peak ampere and spark-ON settings. All other spark cavities will be smaller.

EQUAL SPARK-ENERGY POWER SUPPLIES

One power-supply design does produce sparks with equal energy. It is based on the actual spark-ON time starting from the point of dielectric fluid ionization. Figure 12-4 illustrates this power-supply design concept. When using this type of power supply, the spark-ON and -OFF times are set in microseconds at the control. The set spark-ON time and the actual spark-ON times are always the same. Spark-OFF time is set so that the next spark-ON time does not occur any sooner than the time set by the power-supply-control panel for spark-OFF time. The actual spark-OFF time may continue well beyond the set time, based on a delay in the ionization point of the dielectric fluid. The electrode to workpiece open-circuit voltage is turned on at the end of each set spark-OFF time and is maintained until the next fluid ionization point, whereupon the spark-ON time is again initiated.

Spark-ON time and peak spark amperes are set at the power supply control, prior to starting the machining operation. Peak amperes and spark-ON time determine spark energy, thus, using this power-supply design means that each spark removes the same volume of workpiece material and produces a surface finish of uniformly sized, spherical spark cavities.

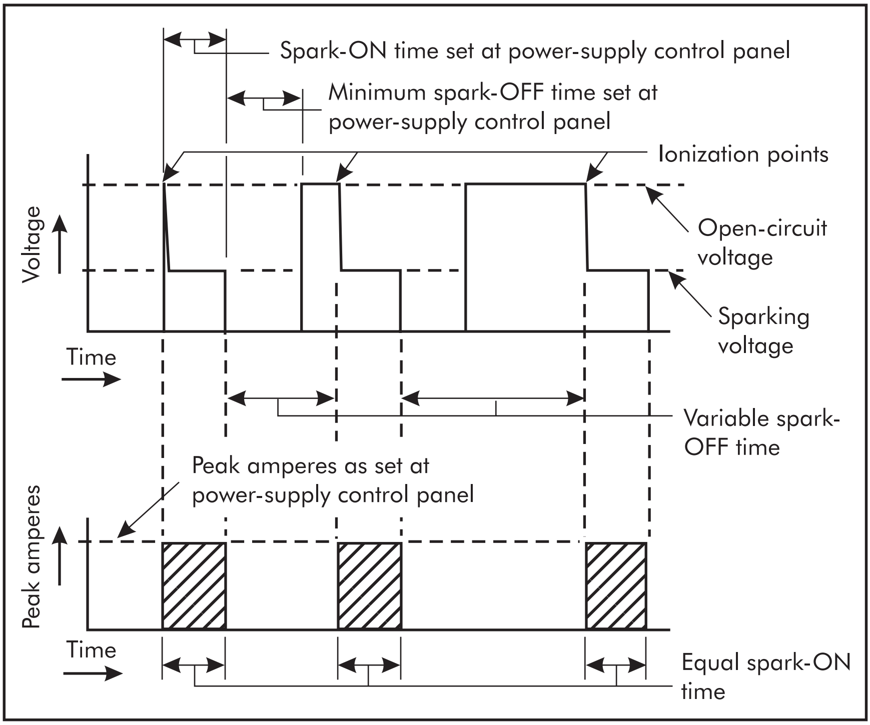


Figure 12-4. Equal spark-ON time and variable spark-OFF time.

The efficiency of the machining operation should be considered when using the equal spark-energy power-supply design. If conditions exist that cause long periods of time between the spark ionization points, completing the machining operation may take an excessive amount of time. The importance of having uniform spark cavities should be evaluated.

EDM SURFACE FINISHES

When inspecting an EDM surface finish, the lack of surface directionality needs to be considered. The surface-finish-inspection device should record the same surface value in any direction. The finest surface finish falls into two categories:

1. Best practical surface finish: 32 R_A µin. (0.8 R_A µm) and
2. Best surface finish: 10 R_A µin. (0.25 R_A µm).

The difference between the best practical surface finish and the best surface finish is time. Fine EDM surface finishes are machined at very low spark-energy levels, using a very short spark-ON time setting and a very low peak-ampere setting. The amount of workpiece material removed per spark is very small. Even when machining at these very low spark-energy settings, the surface finish is not reflective.

EDM METALLURGY

The actual surface finish is only one consideration for EDM, since this is a thermal process and material is removed by heating the workpiece surface. Much of the heat produced by the spark is transferred to the dielectric fluid as the EDM chip cools. The spark also heats the workpiece and this heat must be dissipated through the work-piece and into the dielectric fluid. The temperature within the workpiece spark cavity may be classified into the following zones:

- temperature that vaporizes the workpiece material,
- temperature that melts the workpiece material,
- temperature that affects the workpiece's material structure, and
- temperature that is not great enough to affect the workpiece structure.

Figure 12-5 illustrates the different temperature-range zones within the spark cavity.

Temperature in the workpiece spark cavity decreases as the distance from the spark-cavity surface increases. Long spark-ON time with high peak-ampere machining normally requires finish-machining operations to improve the spark-cavity surface metallurgy. When very high spark-energy machining operations are performed, up to .030 in (0.76 mm) of the rough surface may need to be removed by finish machining in order to provide an acceptable surface metallurgy. The temperature zones within the spark cavity are described in the following sections.

TEMPERATURE ZONE A

Zone A is the surface that is bombarded by spark electricity. Its temperature is high enough to vaporize the workpiece material. Va-

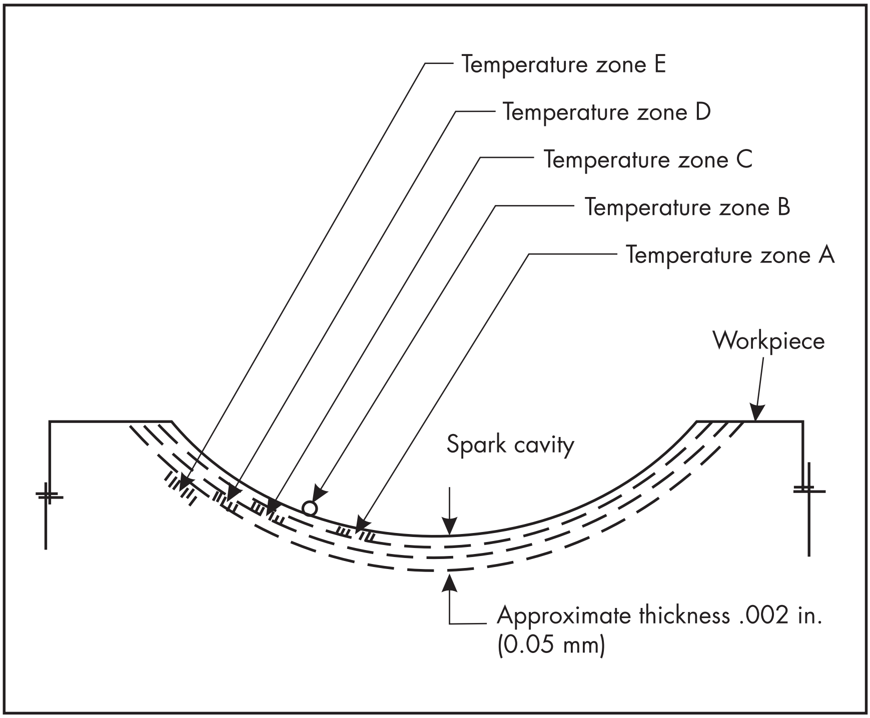


Figure 12-5. Temperature-range zones in the spark cavity.

porized materials from the electrode and dielectric fluid are also included in this area. Most of the vaporized material from the workpiece forms into a cloud and becomes the EDM chip when cooled in the dielectric fluid as the spark is turned OFF. But a small portion of the vapor remains in close proximity to the spark cavity surface when the spark is turned OFF. This material reattaches itself as a layer of the spark-cavity surface and it may contain elements of the electrode material, as well as by-products of the dielectric fluid. Since the material was separated from the workpiece surface and then returned, it is known as the *re-deposited layer*.

The re-deposited layer is very hard, brittle, and highly stressed. This layer is rapidly quenched at the time of spark turn OFF. It may also accumulate a high amount of carbon from the dielectric fluid as it breaks down during sparking. The rapid cooling and high carbon content produces a white layer, or *martensite,* in steel.

TEMPERATURE ZONE B

Temperature zone B is actually part of zone A and consists of spherical-shaped projections that extend from the zone A surface. These small projections are known as *globules* and are often loosely attached to the zone A surface. The globules are actually small amounts of vapor that have separated from the main vapor cloud and remain in close proximity of the spark cavity surface. As the cooling starts at spark turn OFF, the vapor comes into contact with the re-deposited surface layer and bonds to that surface as a projecting globule. These projections are normally very small and appear as specks on the spark cavity surface.

TEMPERATURE ZONE C

The temperature at zone C is high enough to cause the workpiece surface to melt, but not to separate from the spark cavity surface. As the spark is turned OFF, the melted material returns to a solid state. Separately, this layer is known as a *re-solidified layer,* but when combined with layer A, it is referred to as a *recast layer*.

TEMPERATURE ZONE D

The spark electricity heats temperature zone D. Although the heat here is less than the heat at a melting point, it may be hot enough to cause some change in the characteristics of the workpiece material.

TEMPERATURE ZONE E

Material in temperature zone E is far enough away from the surface of the spark cavity that any temperature increase will not affect the workpiece material characteristics. Since material in this zone is not affected by the spark energy, it is classified as *parent material*.

HEAT-AFFECTED ZONE (HAZ)

The heat-affected zone (HAZ) consists of the total spark cavity surface area that has been changed due to the spark heating, namely:

- zone A: the vaporized and re-deposited layer;
- zone C: the melted and re-solidified layer; and
- zone D: the layer with changes to the workpiece material characteristics.

The total thickness of these layers for finish-machining operations is approximately .002 in. (0.05 mm) when using die-sinker machines.

EDM SURFACE CONSIDERATIONS

In many instances the EDM surface finish may be used without additional finishing operations, such as in plastic-injection molds as a decorative surface or in press tooling to hold lubricant so that metal can be formed without galling. EDM manufacturers provide data regarding spark-ON time and peak amperes to produce surface finishes that are acceptable for different applications. They also make recommendations for improving or removing EDM surfaces.

When EDM is used for machining high-temperature materials that are highly stressed in their end use, specifications often define what EDM surface conditions are acceptable. In some instances, the surface must be completely removed. A typical specification for this type of application could include the following items:

- total thickness of the re-deposited and re-solidified layers: .001 in. (0.025 mm);
- total thickness of the re-deposited, re-solidified, and changed material characteristic layers: .002 in. (0.05 mm);
- electrode material present in re-deposited layer: none;
- cracks in re-deposited and re-solidified layers: acceptable (depending on the end use); and
- cracks in parent material: not acceptable.

A cause for concern regarding cracks in high-temperature materials to be used for high-stress applications is that the cracks will propagate and cause part failure.

When using EDM to machine press die tooling, it is possible to produce very sharp corners in the die opening. As piece-part material is pressed through the die opening, considerable force is applied to the die-opening sidewalls. Any sharp corners can become highly stressed and cause failure.

WIRE-CUT EDM SURFACE

The surface characteristics of the wire-cut machine are very similar to those of the die-sinker machine. But its visual appearance is different due to the deionized water that is used as the dielectric fluid. Since water does not have carbon as a by-product as it breaks down in the sparking process, the machined surface remains clean and the chance of DC arcing is minimized. However, consideration should be given to machining any workpiece material with an affinity to absorb hydrogen, since this is a by-product of the water breakdown.

When using rough machining spark energy, followed by low spark-energy finish machining, there is less likelihood of creating temperature zones showing heavily re-deposited and re-solidified layers. This is because less material is removed with each machining pass and at reduced spark energy. The last finish pass may remove only a very small amount of material. This machining technique produces a surface finish that almost eliminates the heat-affected layers in the spark cavity.

Wire-cut computer control in producing required surface finishes offers advantages. Data is input into the computer system specifying surface finish requirements. The computer database then offers a range of settings that will produce the finish. The computer also recommends the number of roughing and finishing passes, as well as the offset required for the electrode wire. This helps ensure that enough workpiece material is left after each pass, so that any detrimental surface conditions are removed or improved during the next pass.

MACHINING HEAT-TREATED MATERIAL

Machining workpiece material in the hardened condition can be beneficial when using EDM. But the benefit should be evaluated when machining large openings against possible distortions of the workpiece. To eliminate, or at least minimize distortion, large openings should be roughed-out prior to the hardening of the workpiece and to machining of the final shape of the opening. Even when using this procedure, the workpiece material may need to be normalized in some instances to remove distortion. This applies to both die-sinker and wire-cut machining operations. But distortion problems are the most noticeable

using wire-cut operations, since computer programming uses the same method for roughing large openings and finishing operations, with only wire-offset considerations made for each pass. Die-sinker machining usually takes into consideration the removal of material prior to EDM machining, because it substantially reduces the machining time.

13 DC Arcing

By definition, EDM is a process that, through precise sparking in the presence of a dielectric, removes electrically conductive material.

NORMAL SPARKING PULSE

From a user standpoint, it is not always easy to determine whether or not the flow of electricity between the electrode and workpiece is controlled versus precisely controlled. In non-technical terms, with a precise EDM spark, the flow of spark electricity starts at the beginning of the spark-ON time and stops at the beginning of the spark-OFF time. Spark-ON and -OFF time is determined by the control setting at the EDM-power supply. Figure 13-1 illustrates a typical spark-ON and -OFF sequence.

ACTUAL FLOW OF SPARK ELECTRICITY

According to the illustration, each time the power supply turns on the spark, the dielectric fluid ionizes. Amperes then flow as spark electricity between the electrode and workpiece. The amperes continue to flow as a spark until the electricity shuts off at the beginning of the spark-OFF time. This timing and flow of the spark electricity is in agreement with the EDM description of a "precisely controlled spark." In reality, many EDM sparks do not occur as illustrated. Instead, conditions existing in the sparking area may not allow the flow of electricity to stop immediately at the same time set as the beginning of the spark-OFF period. Figure 13-2 illustrates this condition.

The peak ampere waveform in the drawing shows that the spark electricity does not immediately turn OFF at the time commanded by the power-supply control. Two possibilities for this are:

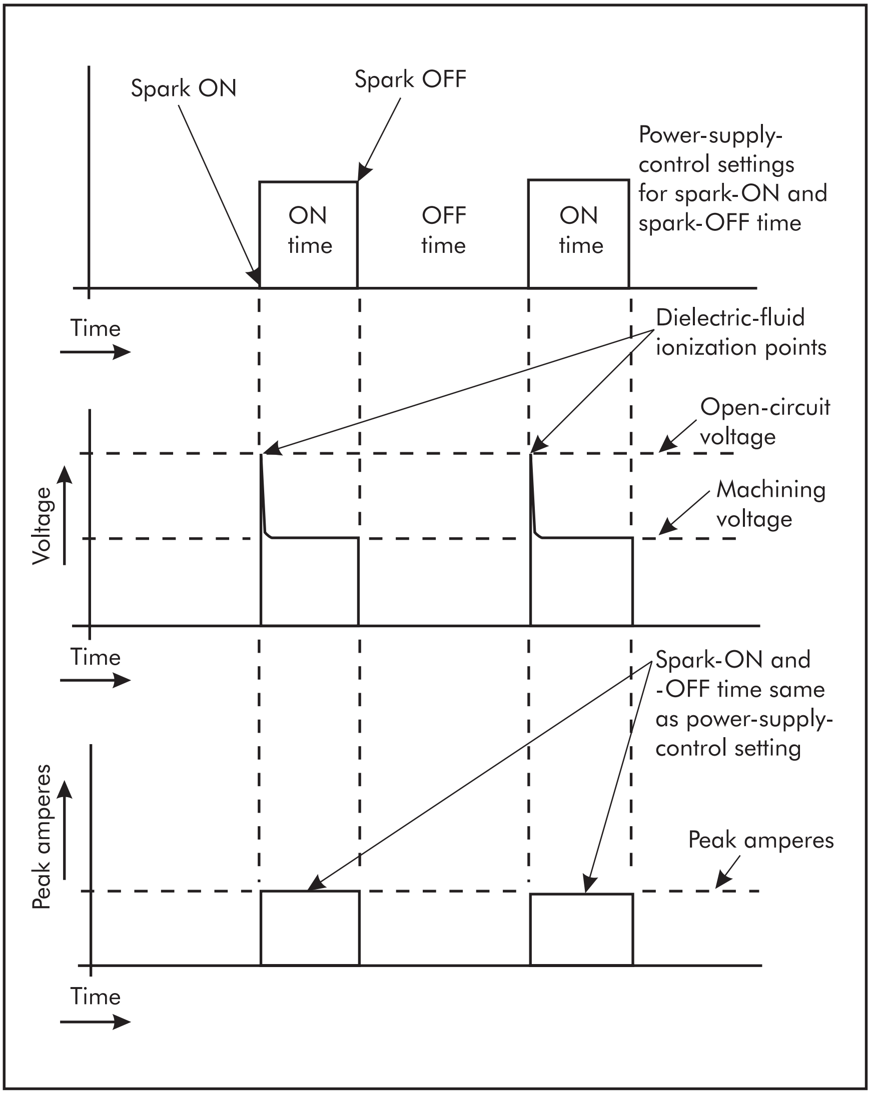


Figure 13-1. EDM-spark timing.

- misuse of capacitors (also called condensers) with an EDM pulse-type power supply. This comment does not apply to capacitors used with resistor-capacitor (R-C)-type EDM power supplies; and
- excessive electrical inductance, caused by separation of the electrode and workpiece sparking wires.

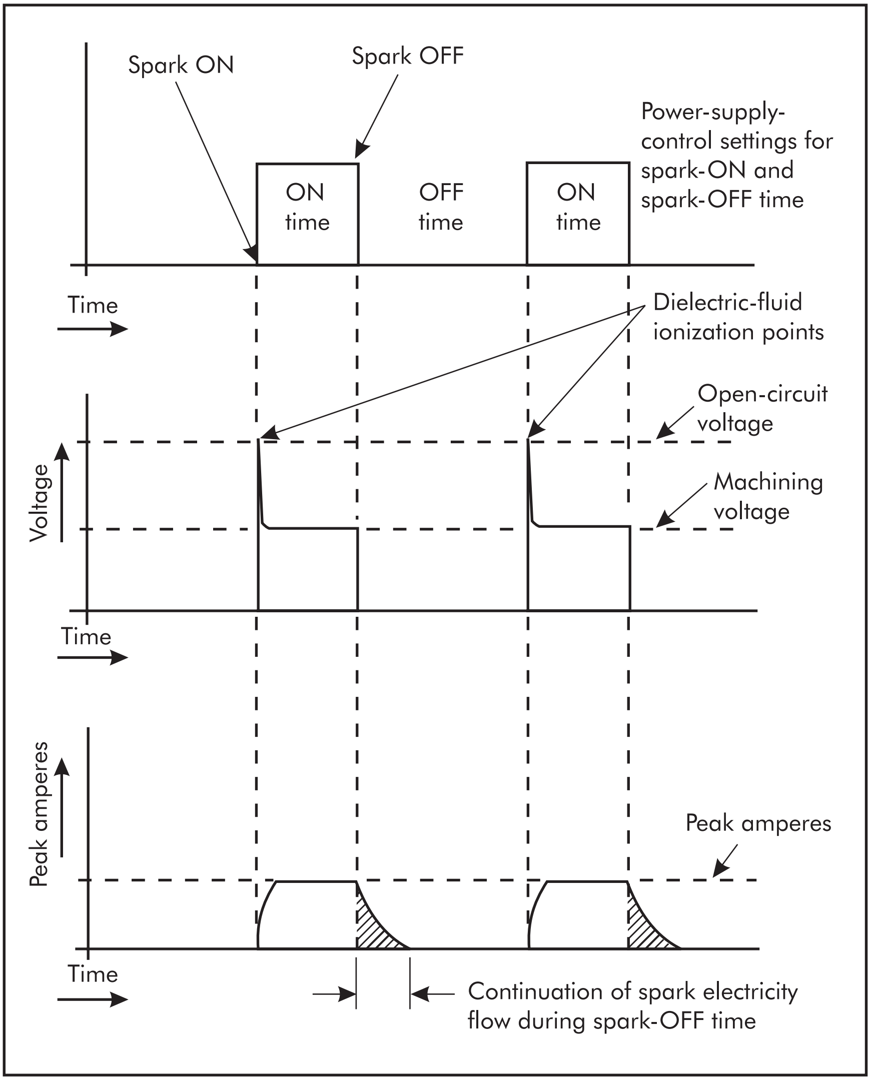


Figure 13-2. Spark electricity flow during spark-OFF time.

ELECTRICAL INDUCTANCE

Misuse of capacitors with pulse-type-power supplies applies only to systems designed to use capacitors to counteract the effect of electrical inductance caused by the separation of the electrode and workpiece

sparking wires. Both misuse of the capacitors and electrical inductance due to separation of the sparking wires cause the electricity to continue flowing during spark-OFF time. Figure 13-3 illustrates separation of the electrode and workpiece sparking wires.

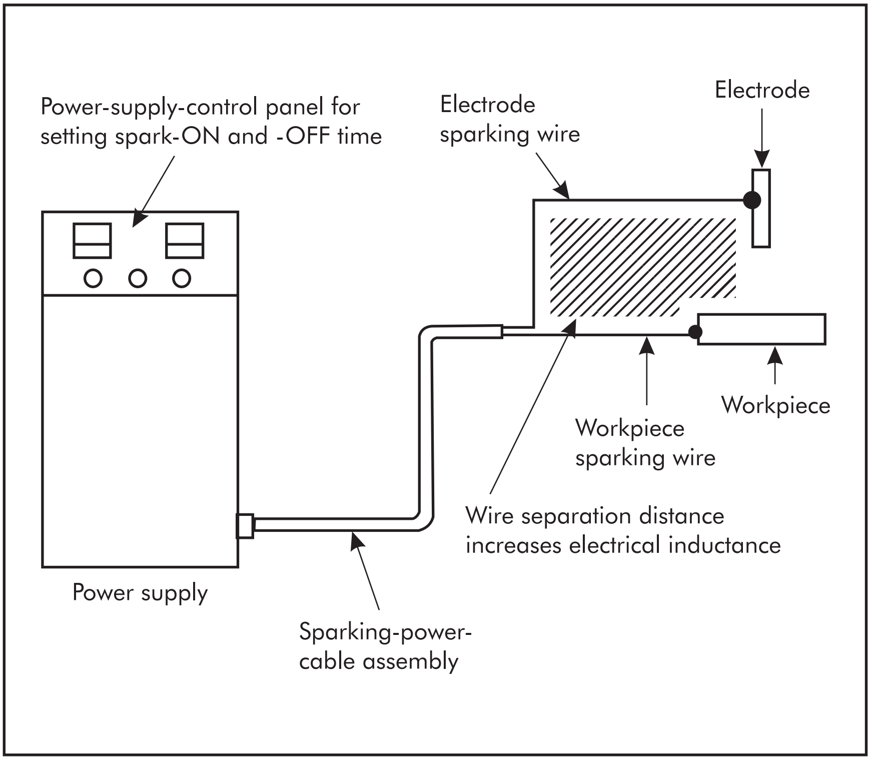


Figure 13-3. Separation of sparking wires increases inductance.

When the spark-OFF time is very long compared to the spark-ON time, the extension of the spark electricity into the OFF time is normally not a problem. In normal die-sinker operation, spark-OFF time is reduced after establishing a stable machining operation. This increases the average machining amperes and reduces machining time. But if spark-OFF time is reduced to a point where spark electricity continues to flow from one spark into the next, there will be no spark-OFF time between the electrode and workpiece, even though the power supply has commanded one. Figure 13-4 illustrates this condition.

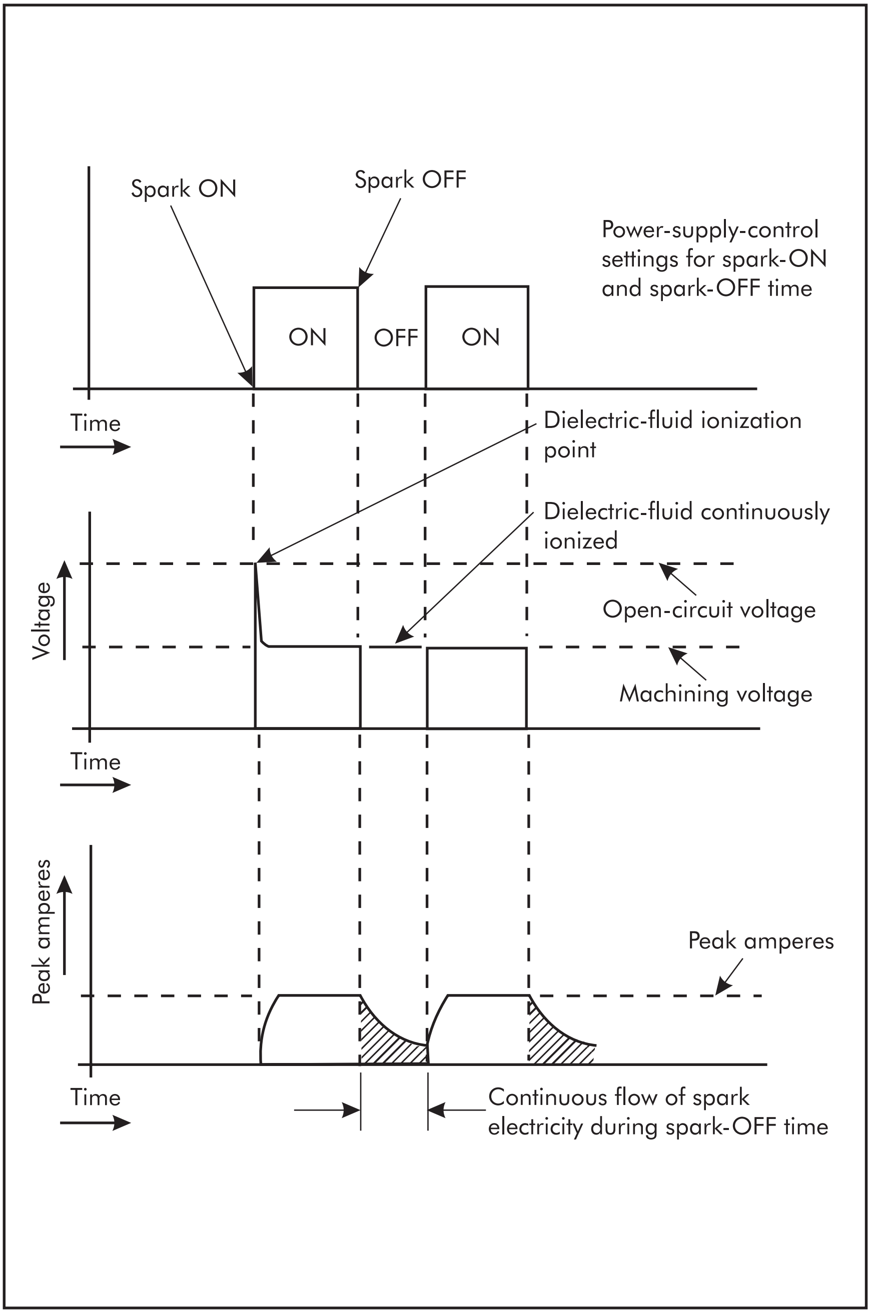


Figure 13-4. Spark electricity extending from one spark to the next.

DC-ARC DESCRIPTION

During spark OFF, when spark electricity continues to flow until it connects to the next spark-ON time, a DC arc starts. Figure 13-4 shows that the power supply has commanded the first spark to be turned OFF. Since spark electricity continues to flow during the complete spark-OFF time, the dielectric fluid remains ionized throughout this time. When the power supply commands the next spark-ON time, the dielectric fluid is still ionized at the location of the last spark and it is at this point that the electricity continues to flow. This cycle continues, resulting in spark electricity flowing continuously at one location, or creating a DC arc.

As the power-supply control attempts to stop or prevent a DC-arcing condition, servo action of the machine becomes erratic. When this type of erratic servo action is noted, the EDM machinist should take immediate action to correct the problem. The first action should be to increase the spark-OFF time until stable servo action is restored. Next, spacing between the electrode and workpiece sparking wires should be made as close as is practical. If capacitors are being used, the capacitance value should be checked to ascertain that it is within the machine manufacturers' not-to-exceed limits.

INDICATIONS OF DC ARCING

When a sustained DC arc occurs, the sparking and servo systems will appear to be stable and operating at 100% efficiency. Machinists need to be observant because the best indicator of a DC arc is the servo-head feed-rate indicator showing no forward movement, even though machining amperes are very stable. In fact, the servo-feed indicator may show a retraction of the electrode from the workpiece while machining appears to be progressing. This stoppage or retraction is due to carbon build-up at the point of the DC arc. The carbon becomes heated and prevents the dielectric fluid from deionizing. As the spark remains at that one location, it will probably cause damage to the electrode and workpiece surfaces. Carbon continues to build up over time as the DC arc continues. This causes the spacing between the electrode and workpiece to increase and the feed-rate indicator to show that the servo head is retracting from the workpiece.

OBSERVANCE OF DC-ARCING CONDITIONS

Experienced EDM die-sinker machinists like to say, "If the machine is operating perfectly, stop the operation and look at the electrode and workpiece, because you probably have a DC arc." Normal EDM operations always display some amount of servo-feed action. Sparking noise should also be monitored, along with the smoke that rises from the sparking area. If the sparking noise becomes quiet and smooth without its normal snapping or crackling, or if the EDM smoke changes from gray to white, a DC arc may have started.

POOR CHIP REMOVAL AND DC ARCING

Dielectric fluid does not necessarily flow equally over all sparking-gap surfaces. Figure 13-5 illustrates this point as it follows the dielectric-flow path exiting from the sparking gap of a square electrode.

Dielectric fluid always exits the sparking area in the direction of least resistance. For a square electrode, that would be from the center hole to the center point on each side. Since there is a greater distance from the center hole to the electrode corners, the corners receive less fluid flow and, consequently, have less than ideal chip-removal conditions. EDM sparking by-products, primarily carbon, also have a tendency to remain in the corners with the EDM chips.

Visually examining the electrode and workpiece surfaces after the electrode has entered the machining area and positive fluid flow has been established will indicate whether the dielectric-fluid flow is allowing the deposit of carbon in the sparking area. Areas that appear darkened with soot are indications of insufficient chip-removal fluid flow. If this carbon material adheres to the electrode or workpiece surface, it is possible for it to heat to the point that the dielectric fluid will not deionize during the spark-OFF time. Sparking will then continue to the point where the heated carbon causes the fluid to remain ionized. As sparking continues at this location, more carbon is added. This type of DC arcing is very difficult for the power supply's anti-arc system to detect, since the spark may be actually turning ON and OFF as directed by the power-supply control but the heated carbon does not allow the dielectric fluid to deionize. If no spark electricity flows during the spark-OFF time, the power supply's anti-arc prevention system

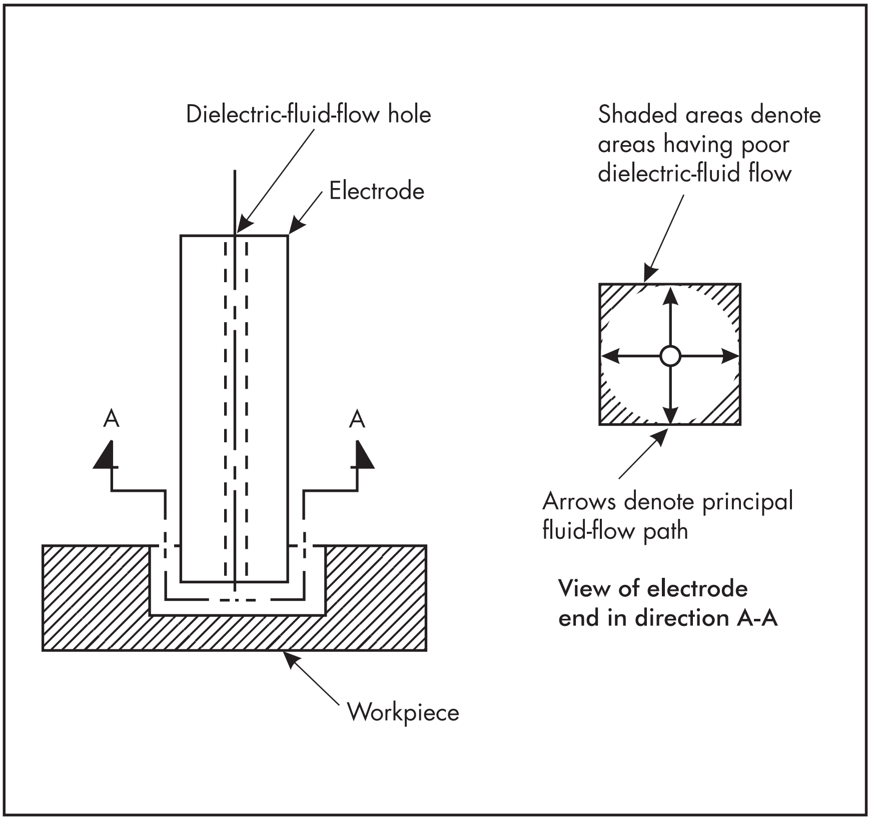


Figure 13-5. Dielectric-fluid flow for a square-shaped electrode.

will believe the sparking system is operating normally and make no attempt to stop the DC arcing. Figure 13-6 illustrates the conditions that exist during this type of DC arcing.

With any type of DC arc, the heat developed from the spark remaining in one location causes a continuous breakdown of the hydrocarbon fluid in that area. This provides more carbon to the arc and causes a carbonized column to increase in height. Figure 13-7 illustrates the growth of the carbonized column in the DC-arcing area.

If a DC arc occurs and corrective action is not initiated, it is possible for the electrode to retract to the point that sparking occurs at or near the surface of the dielectric fluid. At the same time, the heating from the DC arc could sufficiently elevate the fluid temperature until the hydrocarbon fluid ignites from a spark.

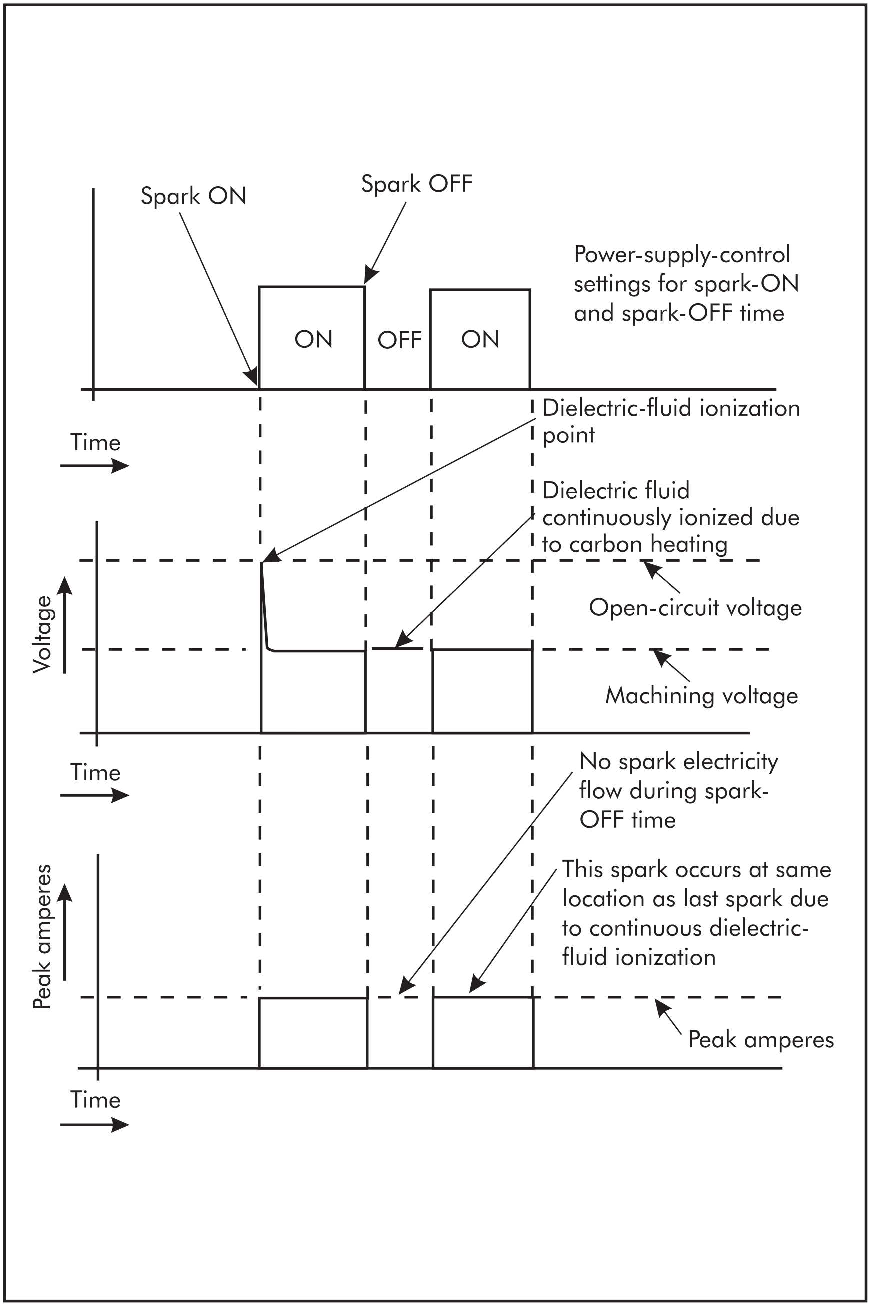


Figure 13-6. DC arcing due to carbon heating.

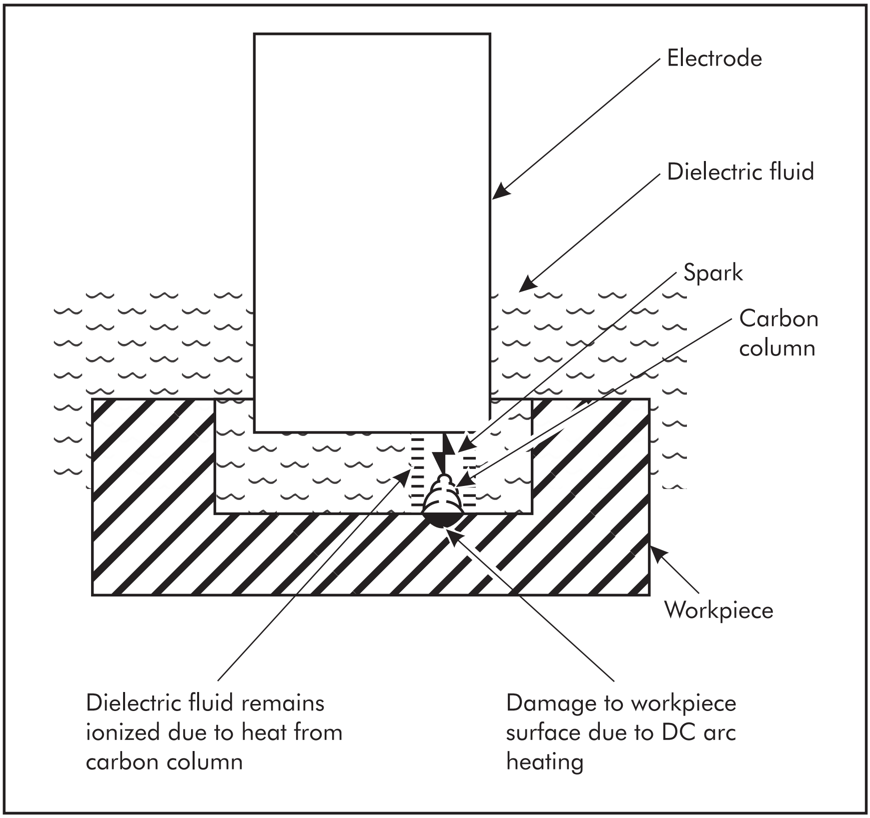


Figure 13-7. Carbon-column growth in DC arc.

DC-ARC RECURRENCE

If a DC arc occurs, it is absolutely necessary to clean all DC arc debris from the electrode and workpiece surfaces to prevent another DC arc from occurring at that same location.

PREVENTING DC ARCS

EDM-design engineers take measures to prevent a DC arc from starting. One system monitors the spark-OFF time to determine if spark electricity is flowing, and if so, the power-supply control can be directed to cancel a number of spark-ON-time pulses. The servo-head feed system can also be commanded to retract the electrode a short distance

and then to return it to the sparking position. This allows time for the dielectric fluid to deionize so that the next spark can occur at a new location, preventing a continued DC arc.

WIRE-CUT MACHINING AND DC ARCING

Normally, wire-cut machinists do not experience DC-arcing problems since the dielectric fluid is usually deionized water and does not produce carbon as it breaks down in the sparking gap. Using a hydrocarbon dielectric fluid for wire-cut machining brings about DC-arcing conditions, but the electrode wire probably would break before damage to the workpiece occurs.

Different Types of EDM 14

There are a variety of ways to machine using electrical discharges. This chapter discusses Electrical Discharge Grinding (EDG), multi-electrode and multi-lead machining, wire-cut multiple-electrode and multiple-workpiece machining, micro-hole EDM drilling and Electrical Discharge Texturing (EDT).

ELECTRICAL DISCHARGE GRINDING

An electrical discharge grinder is a type of die-sinker EDM machine that is referred to as a grinder, due to its appearance. This machine differs from a normal die-sinker machine because the electrode remains stationary while the workpiece traverses under the rotating electrode. Figure 14-1 illustrates the basic EDG machine.

The EDG machine's installation is very similar to that of the die sinker. The EDM-power supply is interchangeable between EDG and die-sinker machines when the same machine manufacturer provides both.

ELECTRODE INSULATION

As in other EDM machines, the EDG electrode must be electrically insulated from the workpiece and machine structure. Figure 14-2 illustrates how this is accomplished by providing insulation between the electrode-mounting hub and the electrode.

If the complete spindle assembly is insulated from the machine and sparking electricity is connected to the spindle assembly, internal bearing sparking can occur and lead to premature failure of the bearings. It is also possible to receive an electrical shock by touching both the spindle assembly components and the machine when the sparking electricity is turned ON. To eliminate this problem, the insulation should

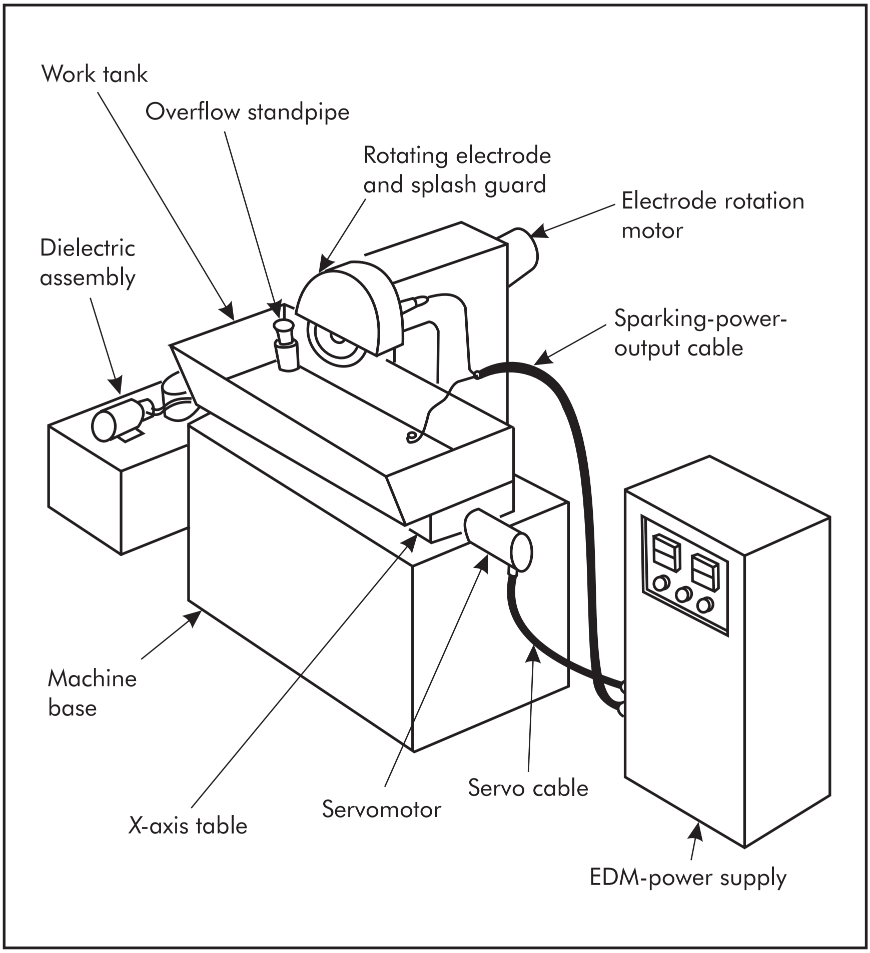


Figure 14-1. Electrical discharge grinder.

be positioned so spark electricity flows directly from the electrode-sparking wire to the electrode.

Electricity is transmitted from the electrode-sparking wire to the electrode through a brush assembly. Dual brushes are often used to prevent the possibility of interrupting the sparking electricity from a single brush lifting from the slip ring. The brushes are spring loaded so that positive pressure is exerted against the slip ring. The wire connection from one brush to the other must be flexible enough to allow the brushes to move individually, without interference from each other.

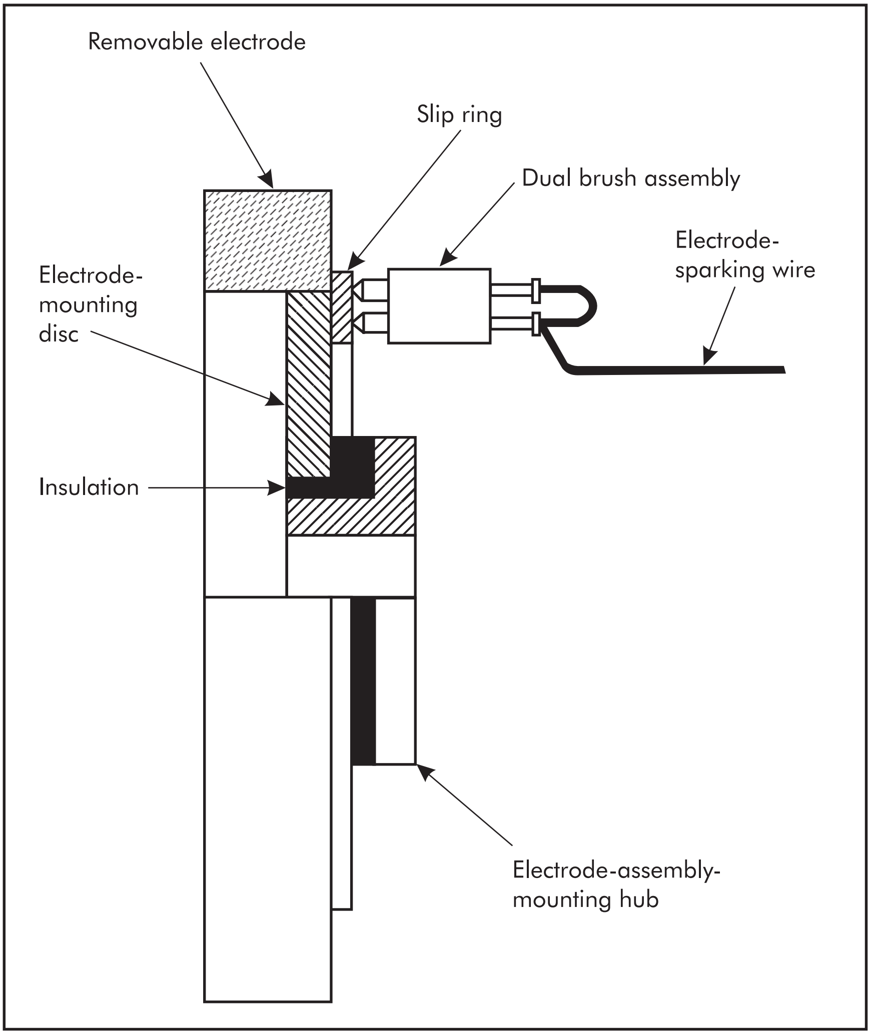


Figure 14-2. Insulated mounting disc isolates electrode from machine.

SPINDLE ROTATION SPEED

EDG electrode rotation is normally in a range of 50–100 rpm. This range is slow compared to a conventional grinding machine. Since the spindle rotation speed is slow and the load presented to the spindle during electrode-dressing operations is high, a specially designed spindle is usually provided for the EDG machine.

ELECTRODE MATERIAL

The EDG electrode is normally graphite, since graphite is easily dressed to the required shape and since it provides good wear qualities. A medium-to-fine particle size graphite material is recommended.

EDG DIELECTRIC SYSTEM

The dielectric system provided with the EDG machine is similar to that of a die-sinker machine. Figure 14-3 illustrates a typical EDG dielectric system.

During EDG-machining operations, dielectric fluid enters the work tank from the filtered dielectric reservoir. The fluid flows through the sparking area, carries the EDG chips in suspension into the dielectric overflow standpipe, and then flows to the unfiltered reservoir. The overflow standpipe is often adjustable to control the dielectric-fluid level in the work tank. The standpipe is also removable for work-tank draining. The standpipe height is adjusted to maintain a high enough fluid level to properly submerse the sparking gap. The flow-adjust valve allows the amount of fluid flowing through the machining area to be controlled. The overflow standpipe must be properly designed to prevent the work tank from being over-filled when the flow-adjust valve is opened for maximum flow.

A second dielectric pump is sometimes included to provide filtered fluid to a nozzle located in the work tank near the sparking area. Fluid from this nozzle keeps the EDG chips and sparking debris from settling in the sparking area.

EDG CHIP REMOVAL

Chip removal for EDG is quite different from the die-sinker system, since fluid-flow holes are not usually provided in either the electrode or workpiece. In EDG, the rotating electrode acts as a fluid pump and carries the dielectric fluid through the sparking gap as it rotates. Chips and sparking debris flow with the fluid from the sparking gap and are carried to the work tank. Figure 14-4 illustrates EDG chip removal.

Since the machine table is servo-controlled, anti-friction ways are normally provided to allow table movement without stick friction. The

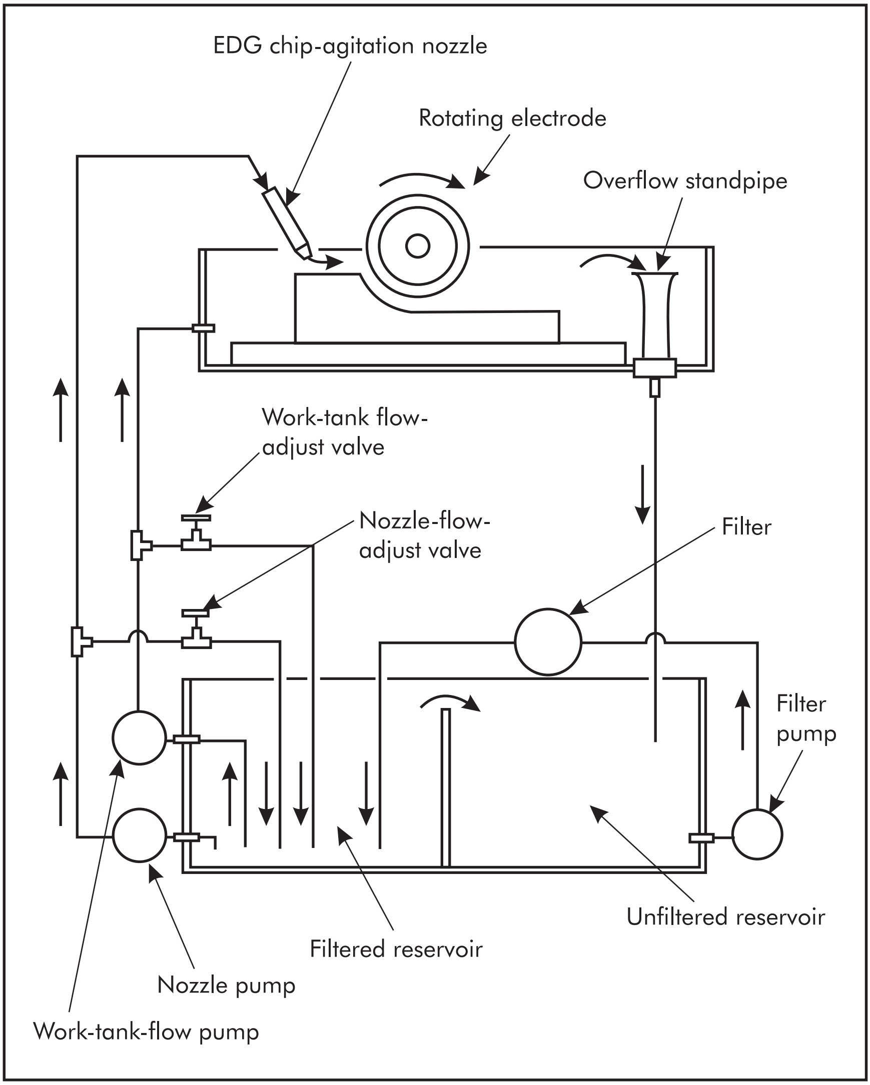


Figure 14-3. Typical EDG dielectric system.

machine-table assembly includes a servomotor that drives an anti-backlash ball screw for table movement.

The EDG machine also includes provisions for manual movement of the table in the *X* and *Y* directions, so that the electrode can be positioned correctly to the workpiece location. *X*-direction movement

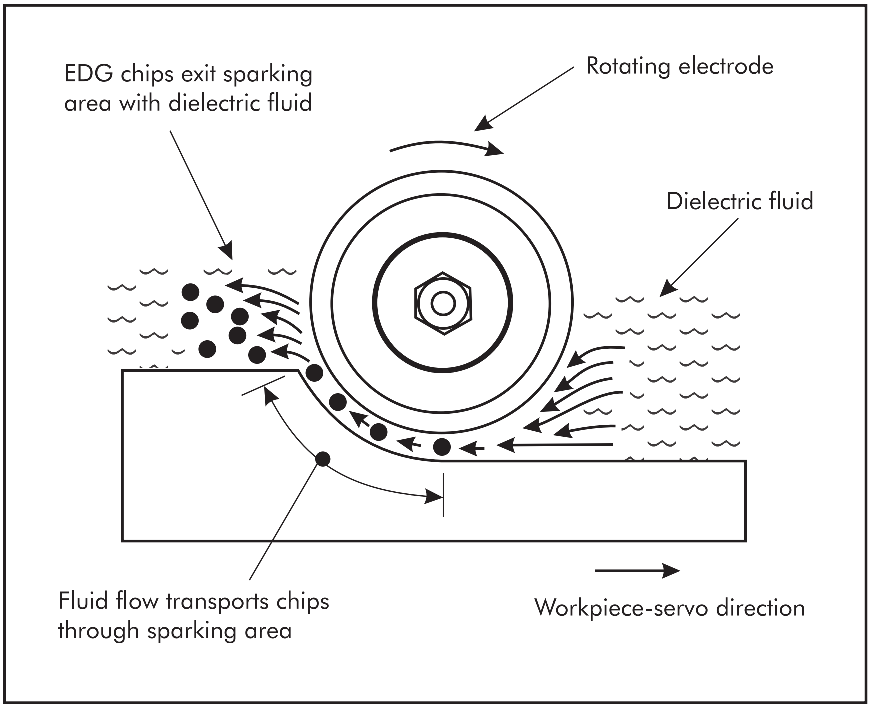


Figure 14-4. EDG chip removal.

is also used for electrode re-dressing when the dressing tool is mounted to the machine's worktable. The *Z* direction is usually manual and is used for vertically positioning the electrode to the workpiece.

HYDROGEN COLLECTION CAUTION

The electrode is covered with a splash guard to contain dielectric fluid as the electrode rotates. As sparking occurs, hydrogen gas is generated and hydrogen bubbles are carried through the sparking gap with the dielectric fluid. It is possible for the electrode's splash guard to be partially submersed in the dielectric fluid, causing the hydrogen to collect inside and at the top of the splash guard. If a spark occurs between the brush and its slip ring, the hydrogen can ignite or, at the very least, it can cause the dielectric fluid to be splashed out of the work tank. It is also possible for the hydrogen to ignite with enough force to cause damage to the electrode and workpiece. The electrode splash

guard, therefore, should be vented sufficiently to prevent hydrogen gas accumulation.

ELECTRODE DRESSING TOOL

When designing a dressing tool for the graphite electrode, the supplier of the graphite material should be contacted for advice. Items such as the rake angle, side clearance, front clearance, and land area must be considered in the design. The supplier usually has useful information on these topics and may even be in a position to recommend the material that should be used for the dressing tool. Graphite is abrasive and the material used for the dressing tool will affect the life of that tool. If using a wide electrode, a shear angle may be recommended for the dressing tool to limit the length of form being dressed into the electrode as the tool progresses through the rotating electrode.

The dressing tool should also take into consideration the final sparking overcut. If the overcut is not designed into the dressing-tool form, the final shape produced by the electrode will be under- or over-sized, depending on whether the form is a male or female shape. When angled walls are to be machined, it is possible to dress the final form in the electrode, and then elevate the electrode to leave material in the workpiece for final finishing. By doing so, it may be possible to use increased spark energy for roughing, prior to finish machining. But care must be taken to ensure that the finishing operation removes all unacceptable metallurgical damage caused to the workpiece material by the roughing operation.

ADVANTAGES OF EDG

There are three distinct advantages to EDG:

1. The electrode is usually 12 in. (305 mm) in diameter. Electrode length is equal then to the circumference of a 12 in. (305 mm) circle, making the actual electrode length equal to 38 in. (958 mm);
2. It is possible to produce rotary form tools by rotating the workpiece as well as the electrode; and
3. It is possible to machine fragile material and shapes without damage, due to high-velocity fluid-flow pressures.

MULTI-ELECTRODE AND MULTI-LEAD EDM

Since EDM machines produce only one spark at a time, it seems impractical to perform machining operations on more than one workpiece at a time. Multiple machining operations performed simultaneously on a single workpiece also seem impractical. But there are times when the use of EDM under these conditions is very practical. The use of multiple electrodes in die-sinker EDM operations is divided into these two categories:

1. multiple-electrode machining, and
2. multiple-lead machining.

The type of multiple-electrode machining selected depends primarily upon the chip-removal conditions that exist.

MULTIPLE-ELECTRODE MACHINING

Multiple-electrode machining uses a standard die-sinker machine and EDM-power supply. But this machining makes use of multiple electrodes, instead of a single electrode. It is very important to understand that when using the multiple-electrode technique, only one spark occurs at any instant. Figure 14-5 illustrates multiple-electrode machining.

Although only one spark occurs at a time, the use of multiple electrodes increases the spark-OFF time and allows additional time for the EDM chip to exit the sparking gap. When additional time is allowed for chip removal, the efficiency of the sparking operation increases, since the next spark occurs in a sparking area, free from EDM chips. This is the scenario that takes place in multiple-electrode machining.

Electrode Ends and Workpiece Sparking Surfaces

To use multi-electrode machining, the electrode ends and workpiece-sparking surfaces must be in common planes, and the two planes parallel. This ensures that when sparking starts, sparks can occur equally at each of the multiple sparking gaps. Since each electrode has an equal opportunity of providing a spark, it is possible to assume that the next spark will occur at a different electrode-to-workpiece sparking gap. This assumption is based on an equal number of

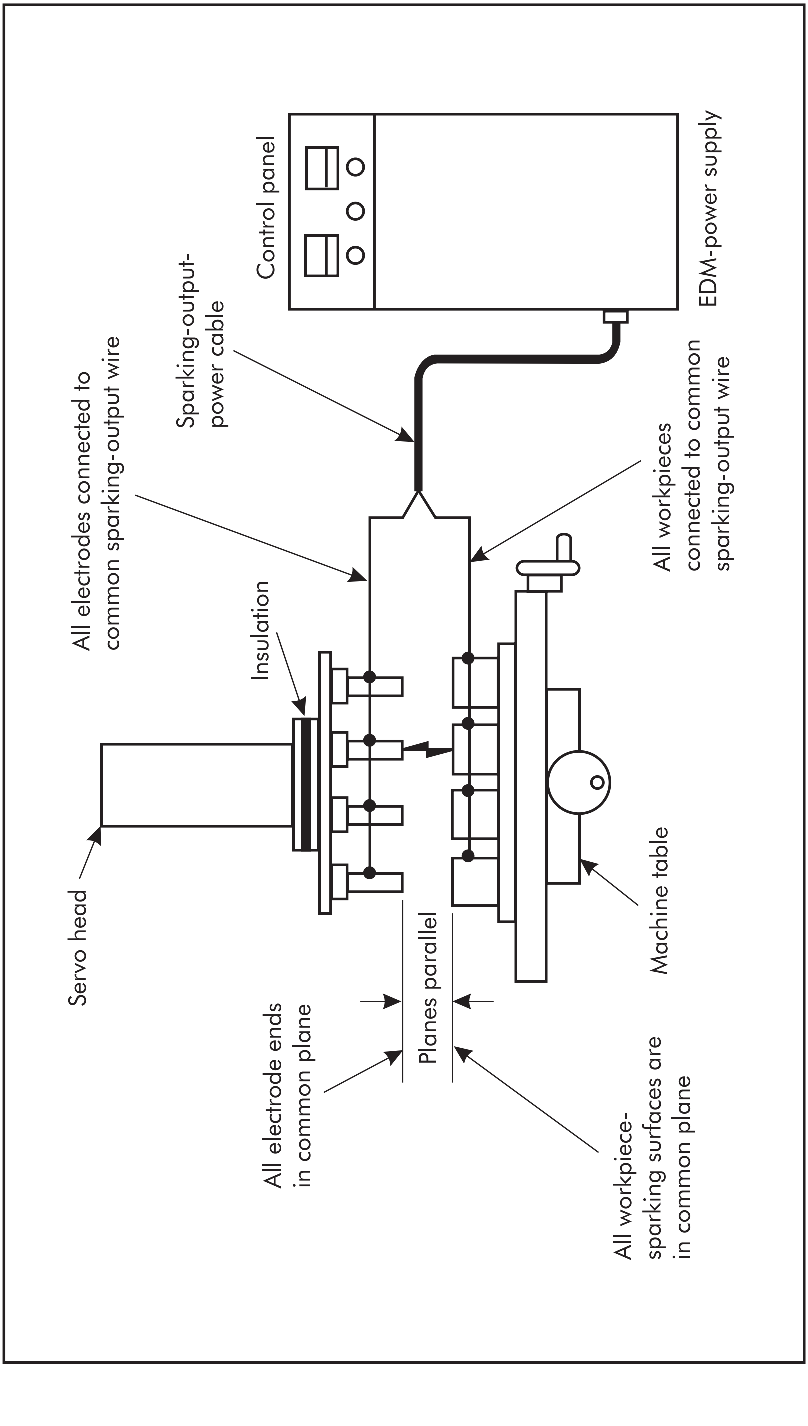


Figure 14-5. Multi-electrode EDM.

sparks being required from each electrode to remove an equal amount of material from each workpiece to complete the machining operation. Figure 14-6 illustrates the sparking pattern for a group of electrodes using this assumption.

Theoretical Sparking Pattern

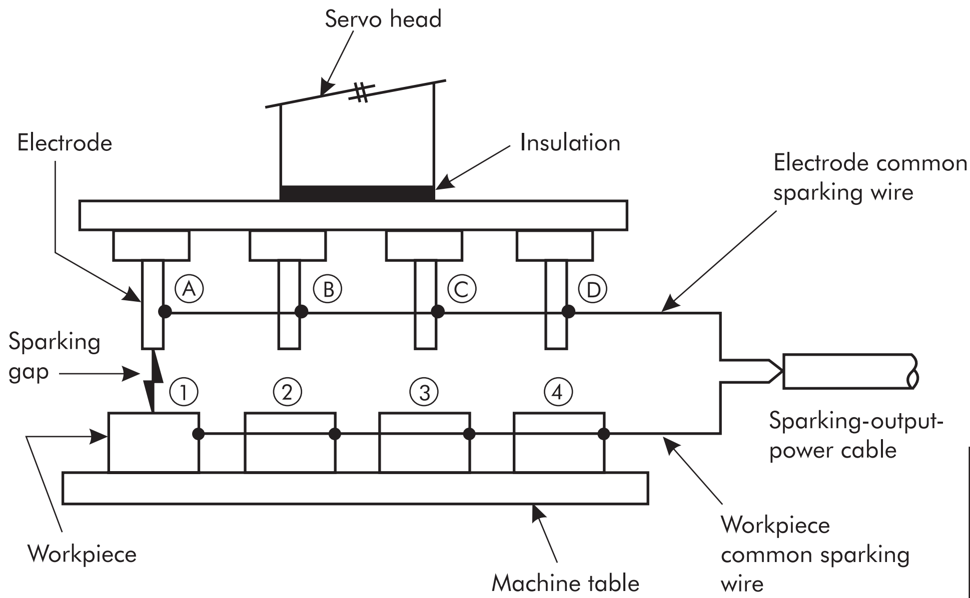
Actual sparking does not follow from A to B to C to D, but rather, it is a random pattern where the actual quantity of sparking gaps determines the spark-OFF time for each electrode. The end result, however, is that the same number of sparks occurs from each electrode to accomplish an equal amount of material removal from each workpiece. Spark-OFF time for each individual electrode is greatly increased. Figure 14-7 illustrates this point.

A high peak-ampere setting should be used with a short spark-ON time with regard to spark energy. This high peak ampere and short ON-time spark ensures that the energy in each spark is great enough to penetrate any layer of chips remaining in the sparking gap. The force of the spark energy is also great enough to keep the chips agitated in each sparking gap, because it facilitates their exit. Spark energy should not be great enough, however, to cause unacceptable metallurgical damage to the workpiece.

Multi-electrode Tooling

Tooling requirements for multi-electrode machining should include the possibility of repositioning the electrode ends. For even though all electrodes must be of the same material, they will not necessarily wear at the same rate. The electrode ends can be set in a common plane in three ways:

1. by unclamping the electrodes and manually setting them to a common reference surface;
2. by designing a device, as part of the tooling, for trimming the electrodes to a common plane; and
3. by using EDM sparking, on a material such as tungsten carbide, to wear away the electrode ends. This may require reversing the electrode polarity to achieve the desired results.



Spark Sequence				
Electrode	1	2	3	4
A	X			
B		X		
C			X	
D				X

Figure 14-6. Theoretical sparking sequence for multi-electrode EDM.

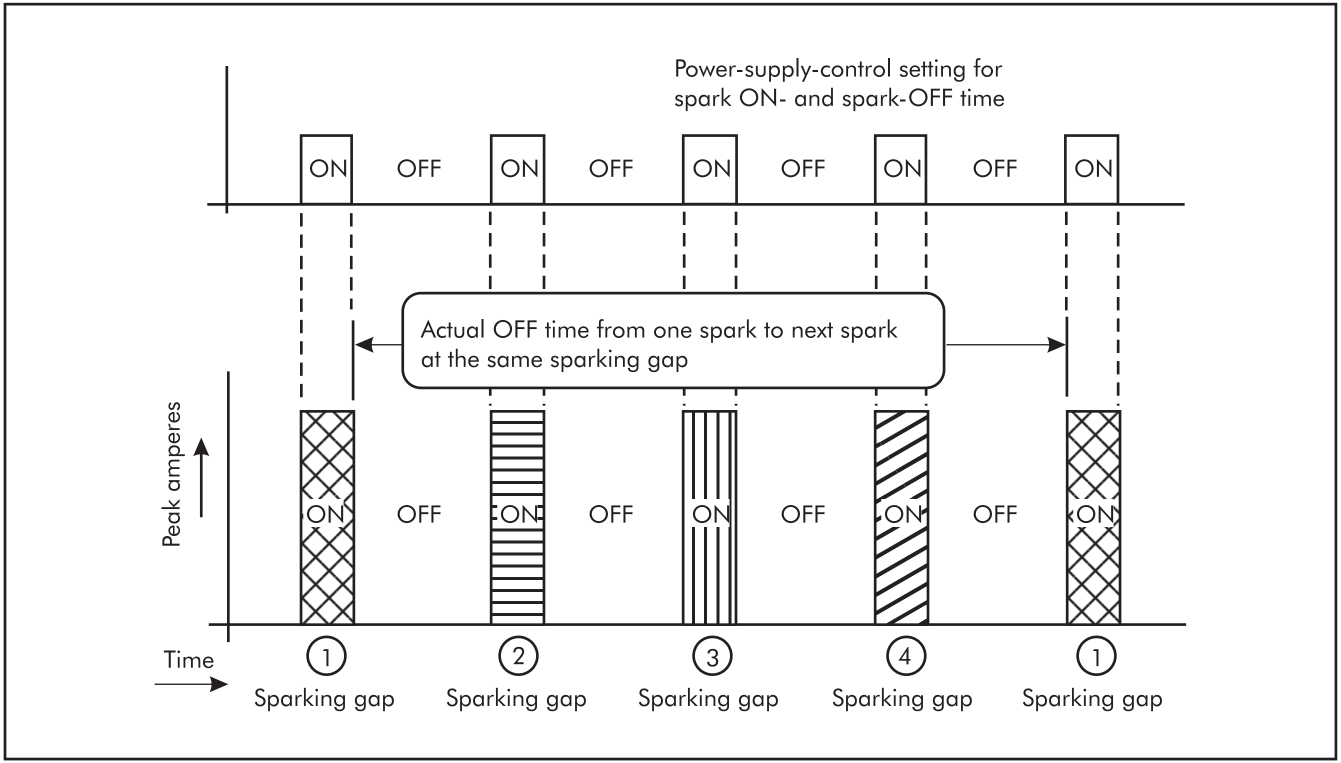


Figure 14-7. Theoretical sparking-gap OFF time for multi-electrode EDM.

Brass is often used as an electrode material for multi-electrode hole-drilling operations because it is inexpensive and readily available. And although brass wears away quickly, it is still considered a good material to use when chip-removal conditions are less than ideal.

Multi-electrode Machining Summary

The following points sum up the basics of multi-electrode machining:

- This process should be considered when multiple machining operations must be performed under poor chip-removal conditions.
- The benefit of using multiple-electrode machining, when poor chip-removal conditions exist, is based on an improvement in sparking efficiency brought about by increased spark-OFF time at each sparking gap.
- There is little or no increase in sparking efficiency through the use of multi-electrode machining for operations having proper dielectric-fluid flow for chip removal.
- If a DC arc occurs, the arc continues at a particular sparking gap, thus causing the forward motion of the servo to stop or retract.

MULTI-LEAD MACHINING

Multi-lead machining differs from multi-electrode machining because a spark may occur at each sparking gap during each spark-ON time. Figure 14-8 illustrates a four-electrode multi-lead machining operation.

Multi-lead machining requires a specially designed EDM-power supply that provides an individual sparking output to each sparking gap. Insulation is required to electrically isolate each electrode from the others. Only one power-supply-control panel is required for all of the power-supply outputs. Spark-ON and -OFF times and peak-ampere output are the same for all sparking gaps. The servo system is designed so that the electrode closest to the workpiece (with the lowest servo voltage) controls the advance and retraction of all electrodes. No particular electrode controls the servo system. Instead, the control changes from one electrode to another, based on the lowest machining voltage of all of the sparking gaps.

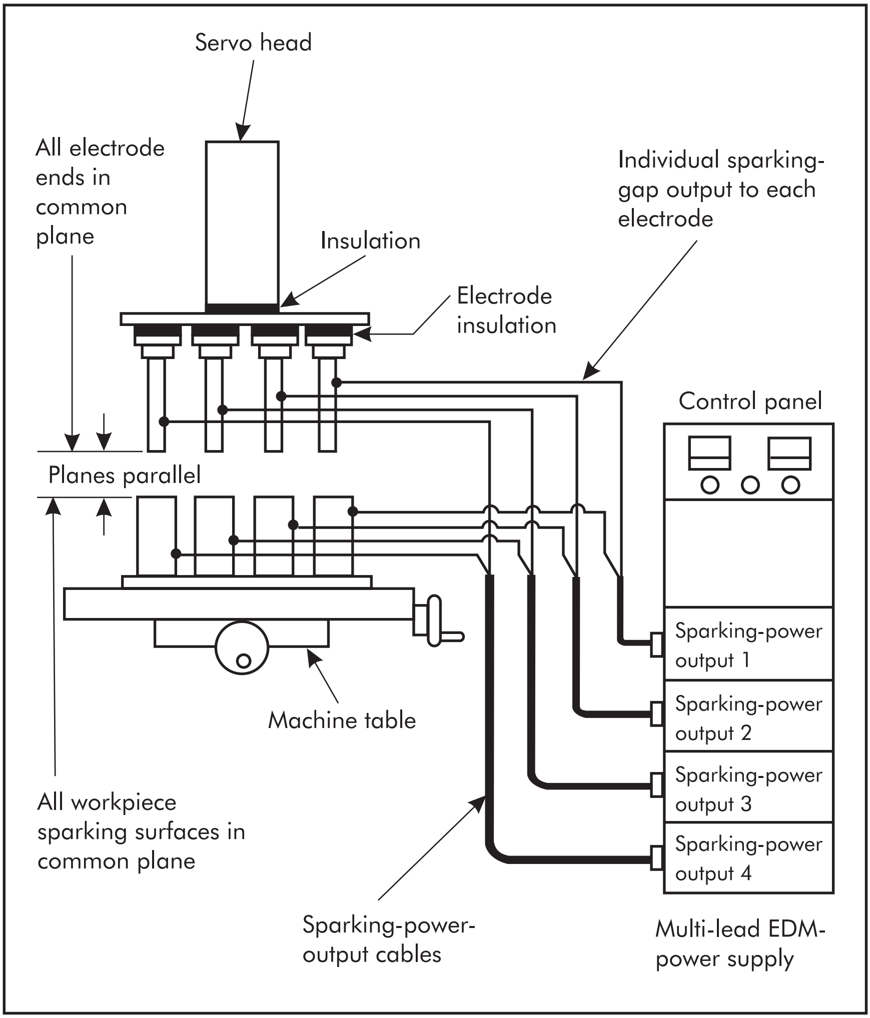


Figure 14-8. Multi-lead EDM.

Chip-removal Requirements

Multi-lead machining is recommended only for those applications with good chip-removal fluid flow. The idea is to be able to machine multiple workpieces in the same amount of time that is required to produce only one workpiece. Without good chip-removal conditions provided by positive dielectric-fluid flow, any one sparking gap might

cause erratic servo operation, which would then affect all of the other sparking gaps. Figure 14-9 illustrates the concept of multiple sparking provided by a single power-supply control.

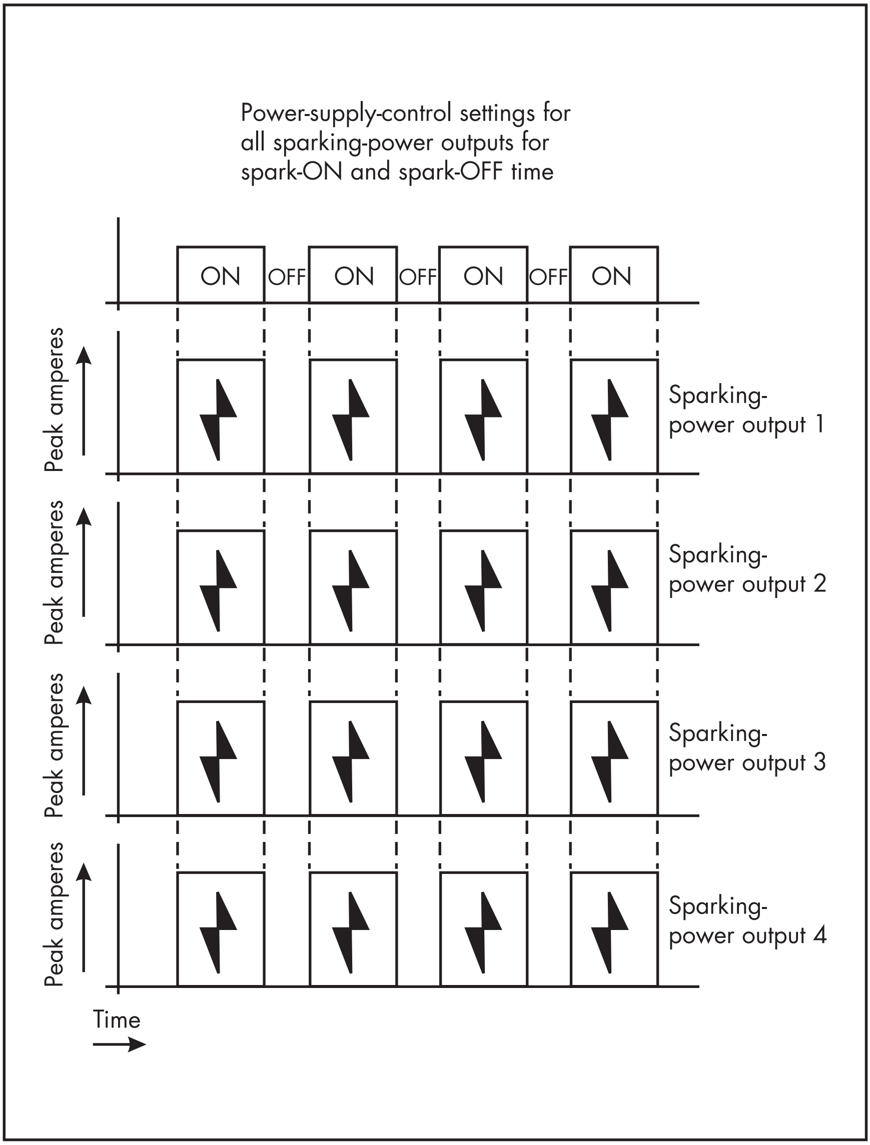


Figure 14-9. Multi-lead spark concept.

Electrode and Workpiece-sparking Surfaces

As with multi-electrode machining, multi-lead machining requires electrode ends and workpiece-sparking surfaces to be in common planes that are parallel. This ensures that the potential for simultaneous sparking exists at each of the sparking gaps.

With proper tooling and good chip-removal conditions, multi-lead machining allows multiple machining operations to be completed in approximately the same time it takes to complete a single operation.

Multi-lead Machining Summary

The following summarizes the basic points of consideration for multi-lead machining:

- Multi-lead machining can use a short spark-OFF time, which increases the average machining amperes and reduces the machining time.
- Servo action is stable with this method and this increases operational efficiency.
- Multi-lead machining should only be used when good chip-removal conditions exist.
- The number of sparking gaps available for multi-lead machining is limited to the number available from the specially designed power supply.
- If a DC arc occurs, it continues at that particular sparking gap causing the servo to hold or retract a position and sparking at all other gaps will probably cease.

WIRE-CUT MULTIPLE-WORKPIECE AND -ELECTRODE MACHINING

This section briefly discusses multiple-workpiece and -electrode machining using wire-cut machines.

MULTIPLE-WORKPIECE MACHINING

Wire-cut machines do not have the same concerns as die-sinker machines when considering multiple machining operations. With wire-

cut machines, the workpieces are stacked and then the stack is machined as an assembly. However, there must be a positive electrical contact from one workpiece to the next, or wire breakage will result.

MULTIPLE-ELECTRODE MACHINING

Some wire-cut machines provide multiple electrode wires for machining multiple workpieces. Others are designed with a single electrode wire to traverse through the first sparking gap, then to the second, and possibly to subsequent sparking gaps. In most instances, these are specially designed, proprietary machines, intended to produce parts in production quantities.

SUMMARY

In general, multi-electrode and multi-lead considerations do not apply to wire-cut operations. Wire-cut operations must use positive dielectric flow for chip removal, or wire breakage will result. The advantage of stacking parts for wire-cut machining is that the sparking area is increased. This allows an increase in sparking amperes that results in a decrease in total machining time.

MICRO-HOLE EDM DRILLING

Micro-hole EDM drilling should not be confused with using EDM machines to produce start holes for wire-cut EDM applications. Micro-hole-drilling machines are specially designed to repeatedly produce high-precision, tiny holes, usually in the range of .003–.012 in. (0.076–0.304 mm) in diameter.

These machines are comparable to die-sinker machines in that a servo head advances the electrode and as it advances, sparking occurs between the electrode end and workpiece. They are also comparable to wire-cut machines in that a wire is used for the electrode and that normally deionized water is used as the dielectric fluid. A direct comparison to either the die-sinker or the wire-cut machines, however, is not really possible. This is because the micro-hole machine is designed for the primary purpose of drilling very small diameter holes in production quantities.

When a single hole is required in the diameter range of .003–.012 in. (0.076–0.304 mm), a standard die-sinker may possibly be used. But when hundreds or thousands of holes are required in this range, it is not practical to consider the standard die-sinker machine. The time required to replenish an electrode as it wears away and the time required to load and unload a workpiece is too labor intensive. The micro-hole drilling machine is designed to automatically advance the electrode as it wears away and, in many instances, the workpiece is automatically loaded, positioned, indexed, and unloaded.

POWER SUPPLY

Usually, a resistor-capacitor (R-C)-type power supply, with a two-ampere maximum output, is used for micro-hole drilling. Spark overcut is approximately .0005 in. (0.013 mm) per side. When the micro-hole machine is computer controlled, the computer determines the spark settings and controls the servo. But normally it is possible to manually fine-tune the servo adjustment to suit actual machining conditions.

SERVO CONTROL

Servo control is accomplished using a DC motor with the capability of communicating with the computer about direction, velocity, and position. Some micro-hole machines are produced with hydraulic servo systems. Computer control eliminates the need for mechanically positioning components that are included for the purpose of compensating for electrode end-wear. Figure 14-10 illustrates a typical micro-hole EDM-drilling machine.

ELECTRODE WEAR COMPENSATION

The CNC monitors servo-system operation and the actual position of the servo-head slide. It also allows the machine to automatically feed the electrode wire from the spool and to compensate for the electrode end-wear. To accomplish this, the servo is returned to a retracted home position. Prior to the start of the next hole-drilling operation, the servo slide is advanced to a preset distance toward the workpiece. The electrode does not contact the workpiece surface at this time. When

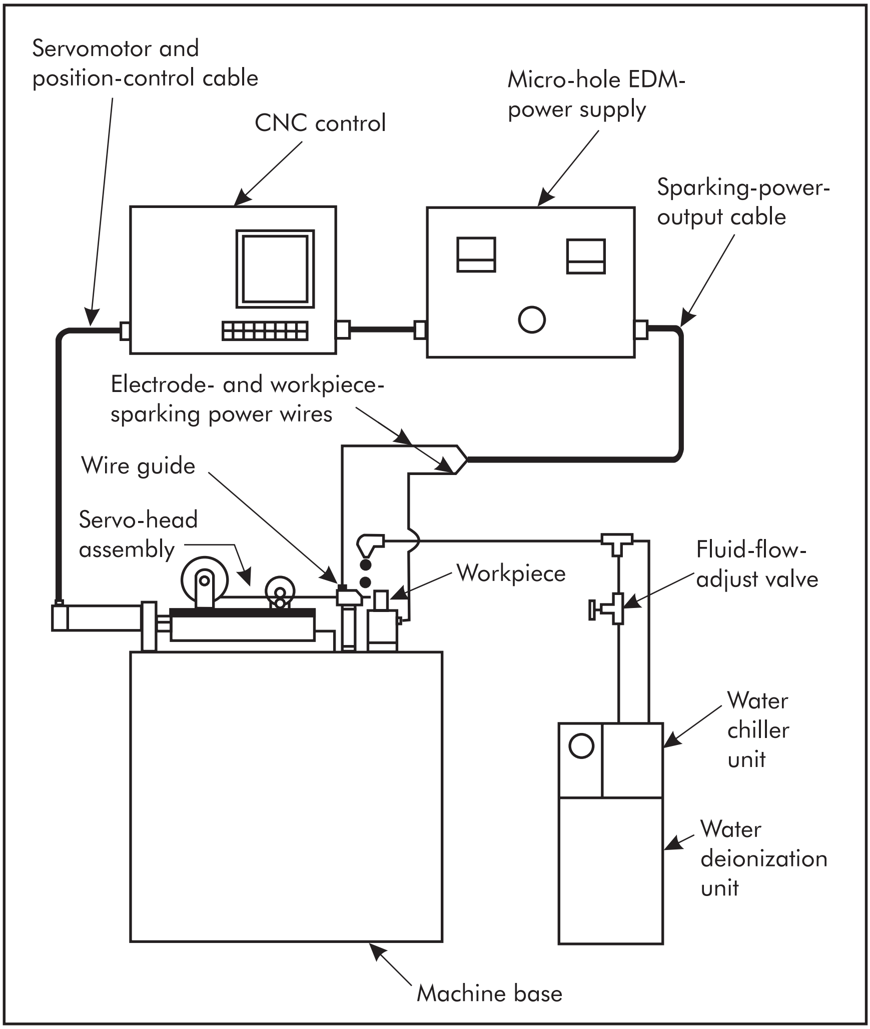


Figure14-10. Typical micro-hole EDM-drilling machine.

the preset advance position is reached, the servo slide stops and holds position. The computer then commands the wire-advance motor to start and voltage is applied between the electrode wire and workpiece. Starting the wire-advance motor causes the wire-feed rollers to rotate and the electrode end advances toward the workpiece surface. The electrode continues to advance until it physically contacts the workpiece surface and the computer system senses a change in voltage from this

contact. The sensing voltage is turned OFF and the wire-advance motor is stopped. Completion of this operation adjusts the electrode length to compensate for previous end wear. The computer then commands the servo motor to retract the electrode an amount that is at least equal to the sparking gap. The electrode is then in a position to start the next hole-drilling cycle.

All components associated with the electrode wire-feed system are mounted on a common base that is electrically insulated from the remainder of the machine. This insulation is necessary to electrically isolate the electrode- and workpiece-sparking wires from each other. Figure 14-11 illustrates the details of the servo-head assembly and the electrode wire-advance components.

ELECTRODE WIRE GUIDE

The wire guide in Figure 14-11 is not actually a part of the servo-head assembly, since it is mounted to the machine base and it remains stationary. The primary purpose of the wire guide is to support the electrode wire as it extends straight out of the guide for a distance of approximately 10 times the diameter of the wire. (Electrode wire should not be expected to remain precisely straight and in line beyond this distance.)

Ceramic is often used as a wire-guide material, since most ceramic materials are electrical insulators. If the wire guide is not created from an insulating material, insulation must be in place between the guide and the machine base's mounting surface. Ceramics can also be precisely machined with the required wire-to-guide clearance so that the wire is properly guided and is able to slide through the guide opening. If there is any looseness between the guide and wire, the electrode will move from the sparking and cause erratic servo action. Any wire movement, other than movement that is in line with the required drilling path, will affect the precision of the EDM drilled hole.

In addition to guiding the wire, the electrode wire guide serves three other purposes:

1. electrical attachment for the sparking-power wire;
2. electrical contact between the sparking-power wire and electrode wire; and
3. attachment point for the dielectric-fluid flow tube.

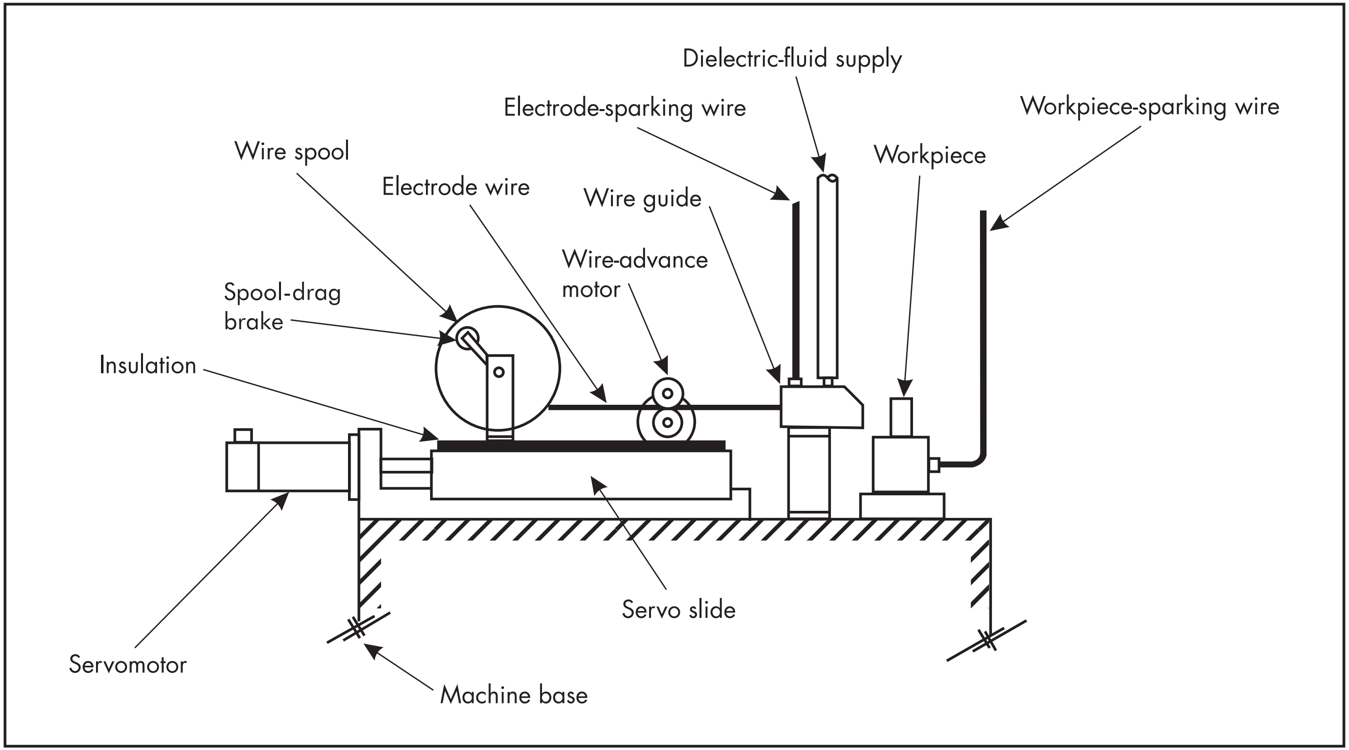


Figure 14-11. Typical micro-hole drill-servo head.

A positive electrical contact must be made between the sparking-power output and electrode wires and it must be as close to the sparking gap as practical. This helps eliminate excessive electrical resistance, which can reduce sparking amperes and cause erratic servo action.

CHIP REMOVAL

Dielectric-fluid flow for micro-hole EDM drilling is minimal. The workpiece is usually not submerged in dielectric fluid. Thus, only one or two drops per second of fluid are needed to transport the EDM chips away from the sparking area and to replenish the fluid surrounding the electrode in the workpiece and the fluid at the sparking gap. Often, the wire guide is used as the supply point for the dielectric fluid, because it allows the fluid to be directed to the workpiece's electrode-entry point.

DEIONIZED-WATER DIELECTRIC FLUID

Deionized water is normally used as the dielectric fluid for micro-hole drilling because water has a low viscosity that allows it to readily enter the hole-drilling area. One primary concern, however, is that the water must flow away from the machining area after use. Since water changes easily from a dielectric to an electrical conductor, if any remains in the sparking area after use, it is possible for electricity to flow through this conductive water and cause damage to the workpiece surface. Appropriate dielectric qualities must also be of concern. In most instances, deionized water that is supplied at the same specification as that required for wire-cut operations, will produce the desired results. It is possible to maintain water consistency through temperature controls that are recommended to ensure the hole diameter does not vary due to variation in temperature.

Since this operation normally requires only a small quantity of water, the water is not reused after EDM micro-hole drilling. Care must be taken, however, to properly dispose of any materials added to the water as a result of EDM drilling because they may be considered environmentally harmful.

ELECTRODE MATERIAL

Normally, tungsten—since it is readily available—is the electrode-wire material of choice for micro-hole operations. It has very good

wear qualities and may be obtained in specified diameters that are accurately maintained.

One concern in using EDM to drill micro-holes is that the AC electrical power for the input to the EDM-power supply may vary. If voltage changes are extreme, they can cause variations in the size of the drilled holes. Some EDM-design engineers recommend adding a constant voltage transformer between the AC voltage source and EDM-power supply. This ensures that the AC-input voltage to the power supply remains within the limits required for the precise spark overcut that is necessary for drilling precise micro-hole diameters.

ADVANTAGES OF MICRO-HOLE EDM DRILLING

There are four distinct advantages to using EDM for micro-hole drilling:

1. Workpieces may be drilled in the hardened condition.
2. There are no burrs produced at the entry- or exit-hole edges.
3. Automatic drilling can be accomplished that includes workpiece load and unload.
4. Multiple machines may be operated with minimal oversight.

ELECTRICAL DISCHARGE TEXTURING (EDT)

Electrical Discharge Texturing (EDT) is an example of using the EDM process to perform a machining operation on a very large workpiece in order to create a uniform, non-directional surface finish without a pattern. This machining operation produces a specified surface on steel rolls of different diameters and lengths. Used for rolling sheet metal, a typical roll would be 28 in. (711 mm) in diameter with a face surface of 80 in. (2,032 mm) to be textured.

ROLL ROTATION AND ELECTRODE TRAVERSE

For roll texturing, the roll is usually rotated at a range of 10–30 rpm. The electrodes are then traversed back and forth across the roll face to completely texture the face surface. EDT machines normally use one of two methods to traverse the electrodes across the roll surface:

1. rotating the roll while maintaining the roll in a stationary position, and traversing the electrodes across the roll face; and
2. holding the electrodes in a stationary position and then traversing the roll past the electrodes while the roll is rotating.

MULTIPLE SPARKING GAPS

Due to the very large roll-surface area, it is impractical to consider texturing the roll with only one electrode and one sparking gap. To reduce the time for texturing, EDM manufacturers have designed machines that use multiple servo heads—each operating individually as separate EDM machines. Each servo head has a servo-drive motor and a sparking-power output that is separate from all other servo heads. Figure 14-12 illustrates a typical EDT electrical connection diagram.

The illustration portrays only one design concept of this EDT machine. Others are available, including machines that use the multiple electrode, single-servo-sparking concept. The illustration is intended only to describe a multiple servo, multiple sparking-gap machine concept and is in no way meant as a recommendation for any particular design or concept.

COMPUTER CONTROL

A computer is used as the master control to provide each sparking output with the same spark-ON and -OFF time, and peak ampere and polarity settings. The surface finish produced by each sparking gap is then identical to all other sparking gaps.

The computer also monitors each servo-drive system so that it responds individually to only a single sparking-gap voltage, without regard to the servo action at any other sparking gap.

Each sparking output is capable of supplying the total number of amperes required to produce the coarsest surface finish texture to be machined on the roll face. It is not uncommon to have 30 A available for each sparking output. Some EDT machines have a total of 50 servo systems and sparking outputs. With 30 A available from each of the 50 sparking outputs, these machines are capable of machining at a total output of 1,500 A.

To accomplish multiple servo machining, it is necessary to have each servo head use a small space so that numerous servo heads can be

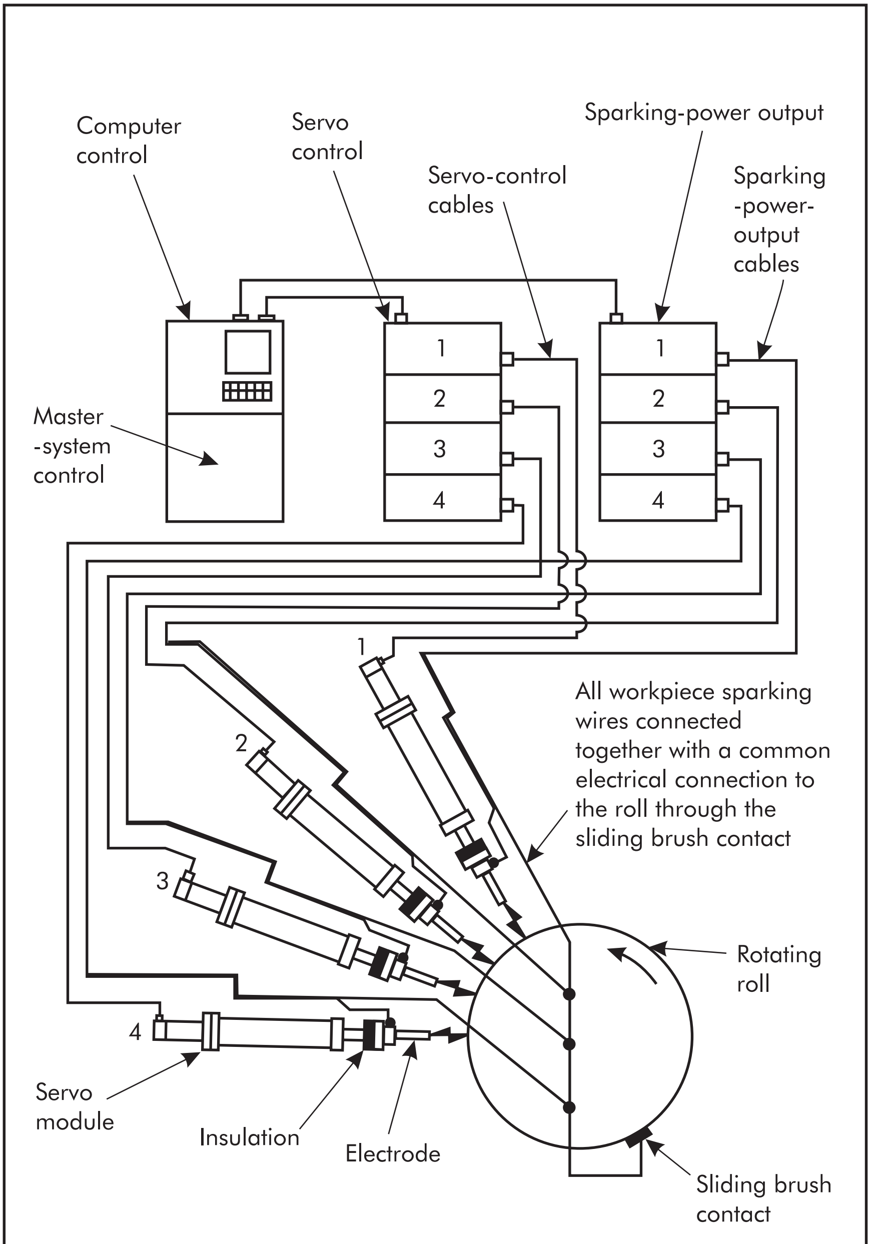


Figure 14-12. Typical EDT machine's electrical connection diagram.

arranged in rows and columns with the electrodes positioned so overlap is provided from one electrode sparking area to another. The servo head is often designed as a modular assembly that is readily removable for maintenance and service. Figure 14-13 illustrates a typical EDT servo-head module design concept.

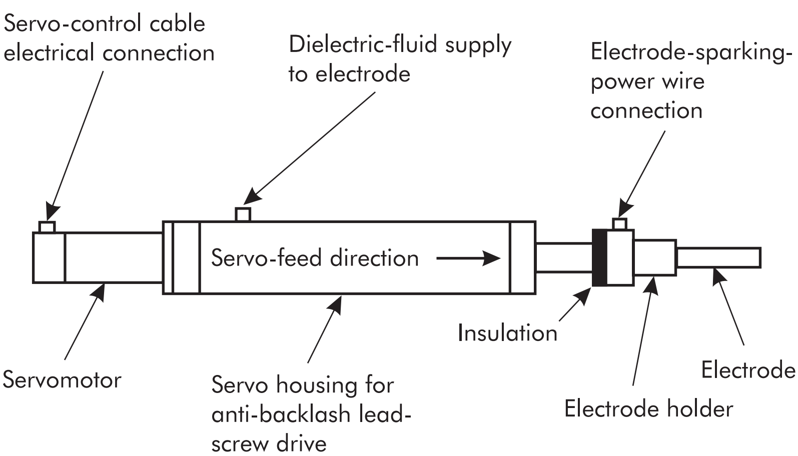


Figure 14-13. Design concept for EDT servo-head module.

Each servo module includes a motor connected to an anti-friction, anti-backlash drive assembly. The drive assembly moves the electrode to and from the sparking surface, as commanded by the computer. As with all other EDM machines, the electrode holder is electrically insulated from the remainder of the machine structure.

EDT ELECTRODES

EDT machines use large quantities of electrodes. Since they are perishable, they should be produced inexpensively. This is why round, copper rod is often chosen as the electrode material. Machining normally consists of cutting off the rod to the required length and then drilling a hole through the electrode on the centerline. The hole is

used for dielectric-fluid flow through the electrode to remove EDM chips from the sparking gap.

Some EDT-machine designers specify copper graphite as the electrode material, because graphite has a lower wear rate than metallic electrode material. Longer electrode life and fewer required electrode changes justify the additional cost for copper-graphite material.

ELECTRODE END AND SPARKING AREA

The electrode sparking area must be taken into consideration for texturing electrodes, especially when worn electrodes are replaced with new ones. Worn electrodes wear the sparking surface to conform to the roll contour, and this makes the complete electrode-end surface available for sparking. When a worn electrode is replaced with a new electrode, the electrode-end surface is flat, which reduces the effective sparking area. Therefore, replacing worn electrodes with new electrodes may require the use of high electrode wear settings for spark-ON time, spark-OFF time, peak amperes, and electrode polarity to allow the electrode end to quickly conform to the roll contour. This procedure increases the electrode sparking area to the size that is necessary to produce the required surface finish.

EDT DIELECTRIC SYSTEM

The EDT dielectric system is very similar to the system used for die-sinker machines because most often it requires the dielectric fluid to be highly filtered. There are other EDT machines, however, that require the dielectric fluid to contain a certain quantity of particles in suspension in order to increase the distance between the electrode and workpiece during sparking. This additional distance allows the dielectric fluid to flow more easily through the sparking gap for chip removal. Figure 14-14 illustrates a typical EDT dielectric system.

The dielectric system for roll texturing requires a large quantity of fluid. The fluid is pumped from the unfiltered reservoir through a filter to the filtered reservoir. The filtered fluid is then pumped under pressure through each electrode for chip removal. Another pump supplies fluid to a manifold and covers the roll surface with dielectric fluid in the sparking area. This fluid surrounds each electrode and contains the sparking gap.

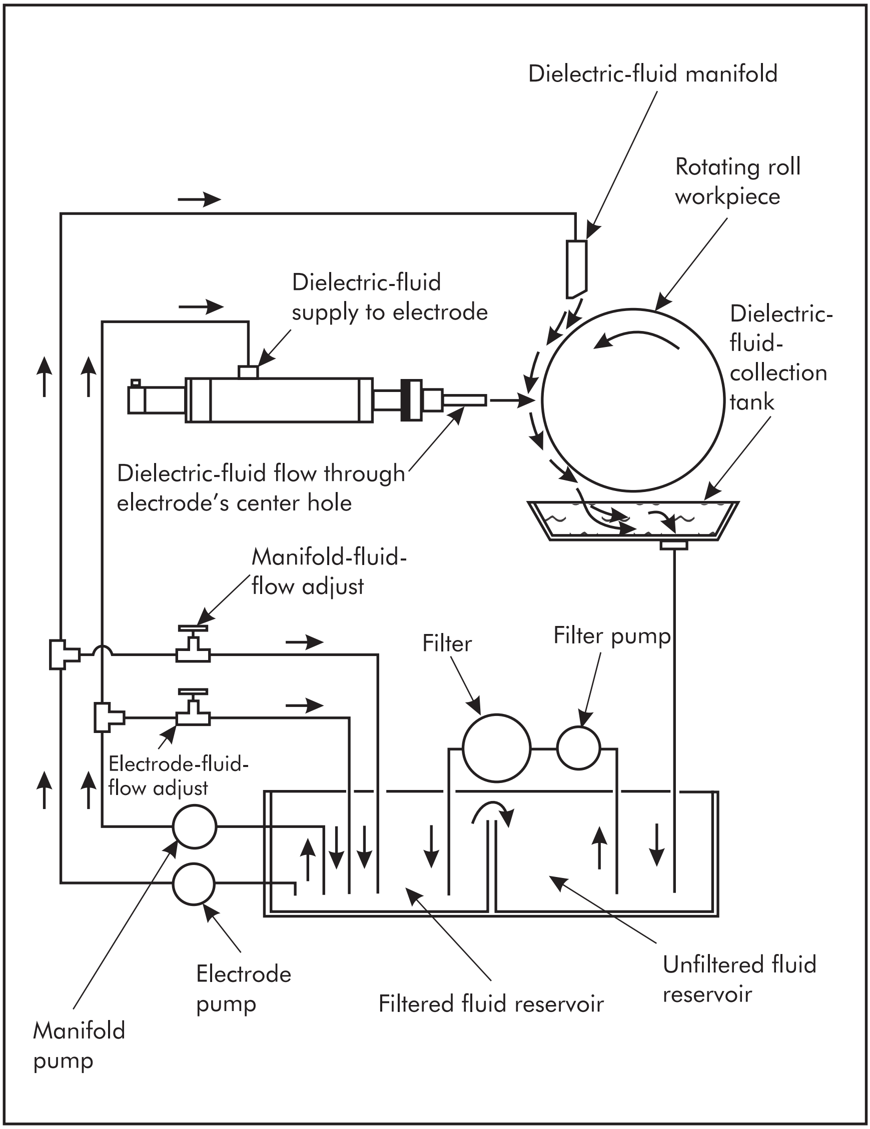


Figure 14-14. Typical EDT machine's dielectric system.

Some EDT-machine designers prefer to immerse the roll in the dielectric fluid, rather than use the manifold to flow the fluid onto the roll surface. In either instance, the sparking gaps must be properly enclosed with dielectric fluid to prevent the possibility of flaming.

Returning the fluid to the unfiltered fluid reservoir completes the fluid flow for the dielectric system. When using the manifold system to cover the sparking area, the fluid continuously drains into the unfiltered reservoir during the texturing operation. If the roll is immersed in the fluid, only the fluid flowing through the electrodes will be returned during the texturing operation. The roll-immersion tank is drained only after the operation is complete.

ADVANTAGES OF EDT

Some of the advantages of using EDT are listed below:

- surfaces may be textured with the roll material in the hardened condition;
- the EDT surface is non-directional;
- the EDT surface is very uniform; and
- use of multiple servo heads, with each head operating independently, reduces total roll-texturing time.

15 Electromagnetic Radiation

This chapter describes the electromagnetic radiation emitted from EDM machines and discusses ways to detect and deal with the radiation.

DETECTING EDM ELECTROMAGNETIC RADIATION

Amplitude-modulated (AM) radio receivers have been used from almost the inception of EDM to monitor the EDM machine operation. When an AM-radio receiver is turned on and the EDM machine is in operation, static is noted in the sound emanating from the loud speaker. The reason for this is that the EDM sparking causes electromagnetic radiation. This condition is also known as *electromagnetic interference (EMI)*. A strong, continuous, static noise usually denotes an efficient machining operation. An intermittent static noise denotes a condition where the servo-drive system is unstable and the electrode is being continually moved to and from the workpiece, causing intermittent sparking. A weak, continuous, static sound from the AM-radio receiver would normally indicate that a DC arc has occurred.

Since EDM sparking may be heard over a very wide area of the AM-radio-receiving band, it can be thought of as a radio-wave transmitter. Figure 15-1 illustrates the reception of radio waves by means of the AM-radio receiver.

Since the static sound made be heard over nearly the entire AM-radio dial (band), it is described as covering a wide spectrum of the AM band. While this condition, called *radio frequency interference* (RFI), is annoying to someone desiring to listen to a radio program, it is very useful when monitoring the operating condition of an EDM machine.

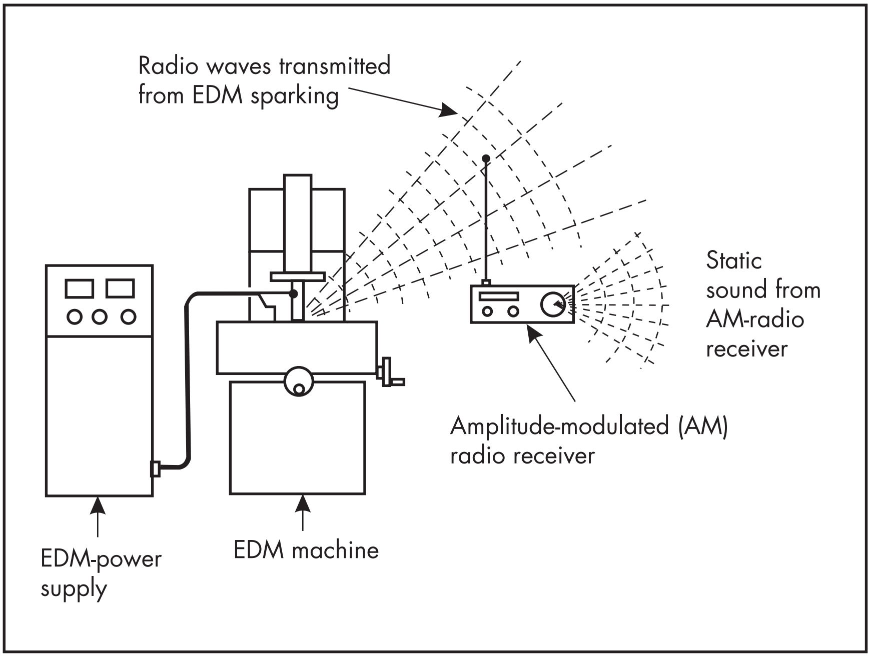


Figure 15-1. EDM sparking causes emission of radio waves.

PLACEMENT OF EDM MACHINES

Placement of an EDM machine in any manufacturing facility must take into consideration the electromagnetic-interference (EMI) radio waves emitted by the sparking. If a radio-controlled lifting crane is in an area where an EDM machine is installed, the operation of the crane could be impaired by the unwanted radio waves from the EDM sparking. Figure 15-2 illustrates this possibility.

With all of the radio-controlled equipment and computer-controlled machines now in operation in many work settings, it is important to note that EDM electromagnetic radiation exists. Special procedures may be required to contain emissions from the EDM sparking. If electromagnetic interference is suspected, the machine manufacturer should be contacted immediately for recommendations on how to eliminate the problem. In some instances, it may be necessary to consult with specialists regarding the elimination of electromagnetic interference.

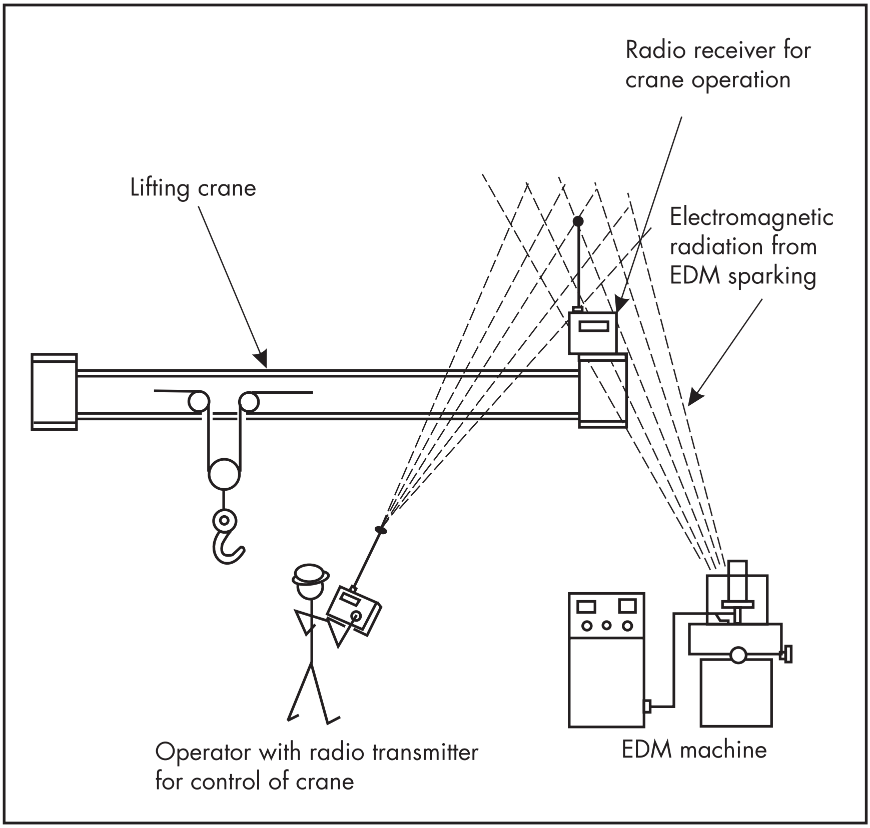


Figure 15-2. EDM sparking may impair the operation of radio-controlled equipment.

MACHINE GROUNDING AND SHIELDING

In general, proper machine grounding will control most EDM-sparking interference. In some instances, a metallic screen cage (sometimes referred to as a *faraday shield*) may also be recommended to enclose the EDM machine and eliminate the electromagnetic radiation. In all cases, the EDM machine must have a proper electrical ground. If a screen shield is required, it too must be properly grounded.

Many countries have laws and regulations about allowable electromagnetic radiation. EDM-machine manufacturers have addressed this condition by enclosing the machine's sparking area within a structure

that reduces or eliminates the sparking electromagnetic radiation. If excessive electromagnetic radiation is suspected, the machine manufacturer should be contacted for consultation.

Glossary

alternating current (AC): An electrical current that flows in one direction and then reverses and flows in the opposite direction.

ammeter: A meter that measures the quantity of current flowing in an electrical circuit.

ampere: The rate of flow of electrons in an electrical circuit. One ampere is equal to 6.24 billion billion (6.24×10^{18}) electrons passing a given point in one second.

amplitude: Used to express the height of the EDM voltage and ampere waveforms.

anti-backlash: System used to eliminate clearance in a mechanical assembly. Removal of clearance is necessary in EDM-servo systems for efficient operation.

anti-friction: System used to reduce friction in mechanical assemblies to improve servo operations.

arc: When used in reference to EDM, an arc is an uncontrolled flow of electrical current between the electrode and workpiece.

arc gap: See *sparking gap*.

atom: The smallest part of an element that can exist. It consists of a nucleus made up of protons and neutrons surrounded by electrons in orbit.

average amperes: When referring to EDM, average amperes are peak amperes multiplied by the duty cycle.

bridge: Description of an EDM machine that has the machining head mounted on a bridge structure over the table area. The head may be positioned in the *X* and *Y* directions over the work area.

burning: An inaccurate description of EDM sparking or spark machining.

capacitor: An electrical component that has the capability of storing an electrical charge.

carbon: An element that is often used as a description for graphite in regard to EDM electrodes. Carbon is not recommended as an EDM-electrode material.

C-frame: Description of an EDM machine having the head-support column at the rear of the working area. The machine head, column, and worktable look like the letter "C" when viewed from the side.

CNC: Abbreviation for *Computer Numerical Control*. Refers to a machine controlled and operated by means of a computer.

condenser: Same as *capacitor*.

cutting current: Electrical current used for sparking and indicated as amperes.

DC arc: The continuing flow of sparking electricity between the electrode and workpiece at one location without movement.

DC power source: The part of the EDM-power-supply assembly that provides the sparking amperes.

deionize: To have the dielectric fluid return to a non-conductor of electricity or to remove an electrically conductive substance from water to make the water a dielectric fluid.

deionized water: Water that has been processed through a resin bed to remove electrically conductive substances.

diatomaceous earth: A material used as a dielectric-fluid filter.

dielectric: When used for describing EDM operations, it normally refers to the fluid used to submerge or encapsulate the sparking area. It describes a material that resists the flow of electricity until a sufficient voltage is applied across a specific distance to cause the material to change to an electrical conductor. For EDM operations, the dielectric is normally hydrocarbon oil or deionized water.

dielectric strength: The electrical rating of a dielectric fluid that determines the point at which it changes from an electrical insulator into an electrical conductor. Normally specified as *volts per mil*.

die-sinker: An EDM machine that uses a shaped electrode to machine the workpiece.

direct current (DC): An electrical current that flows in only one direction.

discharge: With regard to EDM, a discharge is the flow of electricity in the form of a spark.

drift: In EDM, drift refers to the slow movement of an electrode not under servo-system control.

duty cycle: The amount of time the spark is ON, divided by the spark -ON and -OFF times. This may be expressed as a percentage.

EDG: Electrical Discharge Grinding.

EDM: Electrical Discharge Machining.

EDM chip: Sparking material from the workpiece and electrode that is vaporized and then cooled into a sphere with a hollow center.

EDT: Electrical Discharge Texturing.

electricity: Electrical current used as a source of power or the flow of an electrical charge through a conductor.

electrode: The tool used to shape the machined form in the workpiece.

electromagnet: A ferromagnetic core that becomes magnetized when an electrical current flows through a coil of insulated wire that is wound around the core.

electromagnetic interference (EMI): Interference caused by EDM sparking that radiates electromagnetic waves.

electron: A negatively charged particle that orbits around the nucleus of an atom.

erosion: Term used to describe spark machining.

farad: Term to denote the electrical storage capacity of a capacitor. Usually expressed as microfarad when used as a reference to a capacitor.

faraday shield: Term sometimes used to describe a metallic screen cage that may be used to enclose an EDM machine to eliminate electromagnetic radiation.

feed-rate indicator: A device used to monitor the advance rate of the EDM-servo head.

filter: The component or assembly used to remove EDM chips and byproducts from the dielectric fluid.

filtration: The process of removing unwanted material from the dielectric fluid.

flash point: The temperature at which the vapor above a combustible dielectric fluid will ignite and flash when mixed with air, but will not sustain combustion.

frequency: The number of sparks per second as determined by the spark-ON time plus the spark-OFF time.

gap: General term that refers to the sparking distance between the electrode and workpiece. May also be called the *sparking gap*.

gap, frontal: Normally associated with wire-cut EDM to denote the sparking distance between the front surface of the electrode and the workpiece as the electrode advances.

gap-initiation voltage: A voltage superimposed at the start of the spark-ON time to assist in the ionization of the dielectric fluid.

gap, radial: Normally associated with wire-cut EDM to denote the sparking distance between the side of the electrode and workpiece sidewall.

gap voltage: The voltage during sparking.

generator: Same as *EDM-power supply*.

graphite: A material used to produce EDM electrodes.

heat-affected zone (HAZ): The depth that the heat of the sparking has changed the characteristics of the original workpiece material.

hertz (Hz): For EDM, it is the number of sparks per second set at the power-supply control. Also specified as *spark frequency*.

hydrocarbon fluids: Petroleum-product dielectric fluids that break down into hydrogen and carbon during spark heating.

inductance: The characteristic of an electrical circuit or component to resist any change in the flow of electrical current.

inductive reactance: Electrical term for the opposition to the flow of electricity at turn ON and continuing the flow at turn OFF.

insulator: A material or substance that is a poor conductor of electricity.

ion: An atom that has lost or gained one or more electrons.

ionization point: For EDM, the point at which the dielectric fluid changes from an insulator to a conductor of the electric current.

kerf: The slot or opening produced by the wire-cut electrode wire as it machines the workpiece.

kilohertz (kHz): Frequency equal to 1,000 hertz.

machining voltage: The voltage between the electrode and workpiece during sparking.

microfarad (μF): A rating used to indicate the electrical storage capacity of a capacitor.

martensite: See *white layer*.

microsecond (μsec): One millionth of a second in time. Spark-ON and -OFF times are normally set in microseconds.

microsiemens: For EDM, the reference unit used to determine the conductivity of the deionized water for wire-cut machining.

multi-electrode: The term used to describe the use of more than one electrode with only one spark occurring at a time.

multi-lead: The term used to describe the use of more than one electrode at a time with the capability of having a spark occur between each electrode and workpiece at the same instant.

negative polarity: The polarity when the electrode is negative and the workpiece is positive.

no-wear: The term used to describe a condition where workpiece material is impregnated into the electrode surface and the electrode appears not to wear away.
null position: For EDM, a reference to a setting of the servo system where the electrode does not advance or retract.
OFF time: Time between sparks as set by the power-supply control.
ohm: The unit used to describe the resistance of an electrical current to the flow of an electric current.
ON time: Time when the spark's electric current may flow as set by the power-supply control.
open-circuit voltage: Voltage between the electrode and workpiece when the distance between them is too great to allow ionization of the dielectric fluid.
oscillator: Another name for the electronic switch that controls spark-ON/OFF time.
overcut: Clearance produced by the spark and the EDM chips between the electrode and the workpiece.
parent material: The material unaffected by the EDM-spark-energy temperatures.
peak amperes: The machining amperes as set at the power supply.
plasma: The condition of the dielectric fluid in the sparking gap during sparking.
platen: Term used to denote the insulated electrode-attachment point on the EDM machine.
polarity: Term used to denote the electrical polarity of the electrode.
positive ion: An atom with a missing electron, giving it a positive electrical charge.
power supply: The assembly that provides the electric current for sparking and controls the servo system. Also known as a *spark generator*.
pulsating-direct current (DC): The term used to describe sparking power for EDM, where each pulse is a source of energy for a spark.
pulse, spark: One EDM-spark discharge.
pulse-type, power supply: An EDM-power supply that produces a square-wave sparking pulse.
quill: The mechanical portion of an EDM machine that moves at the command of the servo system and to which the electrode is attached. May also be identified as the *ram* of the machine.
radio-frequency emissions: For EDM, the emanation of electromagnetic radiation as a result of EDM sparking.

radio-frequency interference: For EDM, the interference to equipment caused by the spark that may by adversely affected by the radio-frequency radiation of the sparking.

radio-frequency radiation: For EDM, the electromagnetic radiation as a result of EDM sparking.

ram: The mechanical portion of an EDM machine that moves at the command of the servo system and to which the electrode is attached. May also be identified as the *quill* of the machine.

recast layer: The workpiece-EDM surface that consists of material that is vaporized by the spark and re-deposited onto the workpiece. Also includes the workpiece material that is melted by the spark.

rectifier: An electrical device that converts alternating current (AC) to direct current (DC).

resin: For EDM, the material used to deionize water and make it suitable for use as a dielectric fluid.

resistance: The term used to denote opposition to the flow of an electrical current. It is expressed in *ohms*.

resistor: An electrical device or component that is designed to reduce or oppose the flow of an electrical current.

resistor-capacitor (R-C) power supply: An EDM-power supply that generates sparks by the charging of a capacitor through a resistor.

sensing voltage: For EDM, the sparking voltage used for control of the machine's servo system.

servo: The EDM system that controls the electrode advancement and retraction during spark machining.

servo, DC motor: An EDM-servo system that uses a direct-current electric motor for advancing and retracting the electrode.

servo, hydraulic: An EDM-servo system that uses a hydraulic unit for advancing and retracting the electrode.

shielding: For EDM, a barrier that surrounds the sparking area to reduce or eliminate the electromagnetic radiation interference from the spark.

siemens: The unit of electrical conductance formerly called the *mho*.

skim cutting: A term for partial-wire, finish machining that provides a sparking area of less than 180° of the electrode wire diameter.

solid state: Any semiconductor device.

spark: The controlled electric discharge between an electrode and workpiece through an ionized dielectric fluid.

spark machining: Another name for EDM.

sparking area: The area over which sparking occurs.
sparking gap: The distance between the electrode and workpiece during sparking with the dielectric fluid in an ionized condition.
square wave: The waveform produced by turning the sparking voltage ON and OFF when using a pulse-type EDM-power supply.
sublimes: When a solid goes directly to a gas without melting or going through a liquid state.
suction: For EDM, the reduction of pressure in a dielectric-fluid system that causes the fluid to flow from a higher to a lower pressure.
surface finish: The EDM-machined surface produced by sparking.
switch, float: An electrical switch that is actuated by a float device and used to monitor the dielectric-fluid level in the machine's work tank.
taper: For EDM, the angular sidewall tapering caused by side sparking as a die-sinker electrode proceeds into the workpiece.
transistor: A semiconductor device that switches, regulates, or amplifies by electrical means.
traveling wire: An EDM machine that uses a moving wire as the electrode.
vacuum: See *suction*.
vacuum tube: An electronic device that produces electrical current through the heating of a cathode.
vibrator: For EDM, a device used to cause the electrode to move up and down in a vertical direction over a controlled distance that then causes agitation of dielectric fluid in the sparking gap for removal of EDM chips.
viscosity: A measure of a fluid's resistance to flow.
voltage, gap-initiation: A voltage superimposed at the start of spark-ON time to assist in the ionization of dielectric fluid.
voltage, machining: The voltage between the electrode and workpiece during sparking.
voltage, open-circuit: Voltage between the electrode and workpiece when the distance between the two is too great to allow ionization of the dielectric fluid.
voltage, sensing: For EDM, the sparking voltage used for control of the machine's servo system.
voltmeter: A meter used to measure the voltage in an electrical circuit.
watt: Unit of electrical power used to define the rate at which work is done in an electrical circuit; watts = volts × amperes.

waveform: A graphic illustration of an electrical condition, such as voltage or amperes, over a period of time.

white layer: A surface condition caused by the rapid quenching of vaporized and melted ferrous material in the dielectric fluid. This material has a high carbon content and becomes martensite. This martensite appears as a white layer during metallurgical inspection.

wire-cut: An EDM machine that uses a moving wire as the electrode.

work tank: Enclosure surrounding the machine work area that is used for submersion of the workpiece.

workpiece: Material on which EDM is performed.

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ASM International. Materials Park, OH.
E-mail: cust-srv@po.asm-intl.org Web: http://www.asm-intl.org

EDM Technology Transfer. Orem, UT. E-mail: info@edmtt.com
Web: http://www.edmtt.com

Society of Manufacturing Engineers (SME). Dearborn, MI.
E-mail: service@sme.org Web: http://www.sme.org

University of Nebraska-Lincoln, Industrial & Management Systems Engineering Department. Lincoln, NE.
E-mail: iermraju@engunx.unl.edu

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